PHYSICS 30

Module 5

Magnetism

Distance Learning

Alberta EDUCATION

Physics 30

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Magnetism

Alberta EDUCATION

Distance Learning

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Other	

Physics 30
Student Module
Module 5
Magnetism
Alberta Distance Learning Centre
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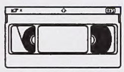
Welcome to Module 5!

We hope you'll enjoy your study of *Magnetism.*

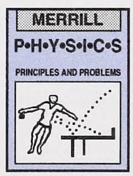
To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.



You also have the option of viewing laser videodisc clips when you see the bar codes like this one.

Frame 4850A

When you see this icon, study the appropriate pages in your textbook.



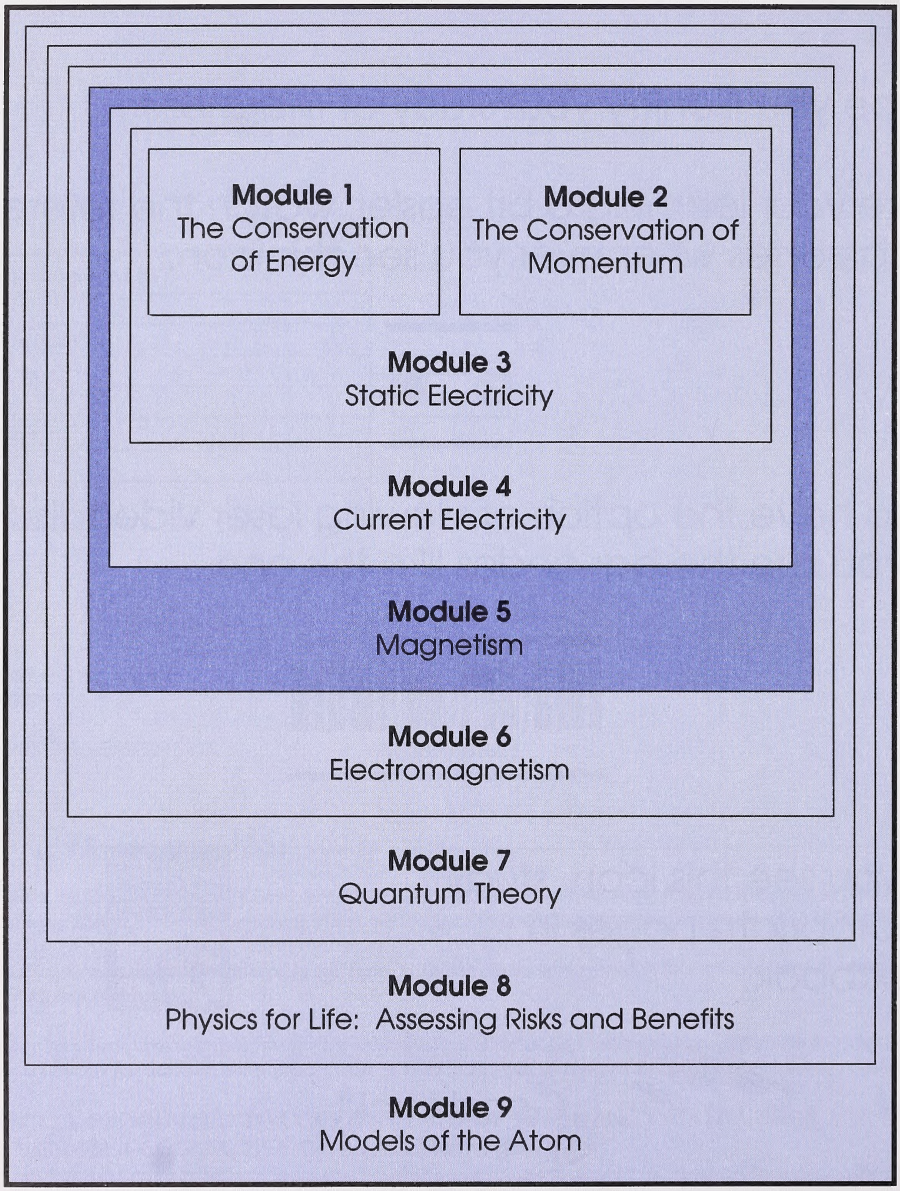
Good Luck!

Course Overview

This course contains nine modules. The first two modules develop the conservation laws of energy and momentum. The conservation of energy is at the heart of the entire course. Modules 3 through 9 build one upon the other and incorporate the main ideas from the preceding modules.

The module you are working in is highlighted in a darker colour.

PHYSICS 30



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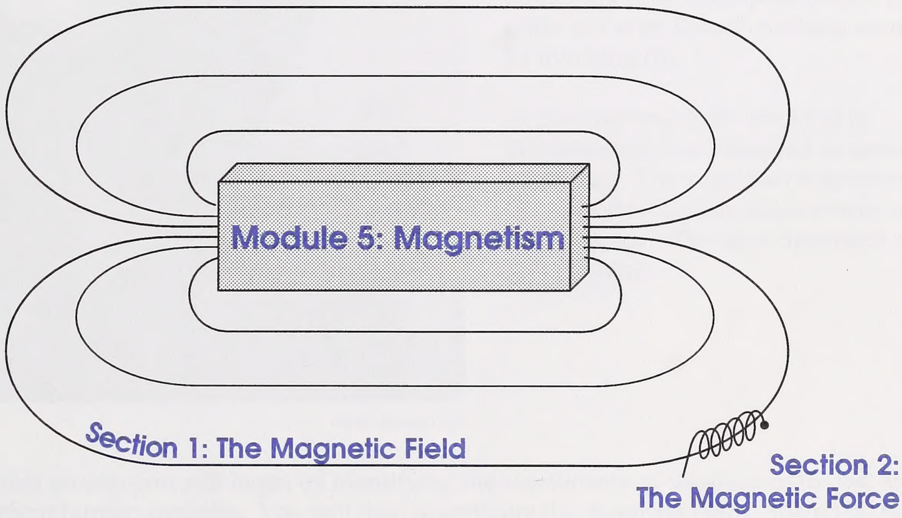
OVERVIEW

Imagine that you are walking with a friend on a winter night. The clear sky has caused the temperature to drop, but you don't mind because the fresh blanket of fluffy snow has made the evening very quiet. You glance up towards the north sky and your eyes are immediately captured by a spectacular display of colour – the aurora borealis, or northern lights. The sheets of colour are mostly shades of green, but you occasionally see streaks of blue and purple. As you continue walking, your friend asks, "What causes the northern lights?"

How would you answer this question? Would you know that part of the answer involves charged particles in the atmosphere being caught in Earth's magnetic field lines?

In this module you will investigate magnetic fields and you will explore the forces that magnetic fields can exert on charged particles. The applications will include a variety of interesting phenomena, including the northern lights.



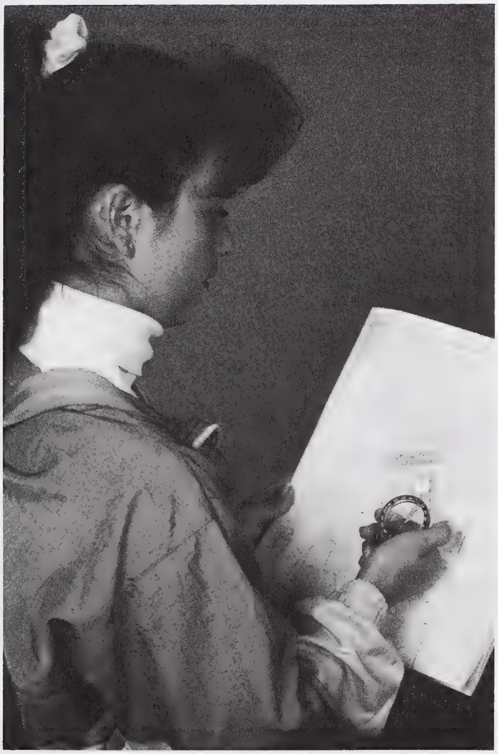
Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete two section assignments. The mark distribution is as follows:

Section 1 Assignment	40 marks
Section 2 Assignment	60 marks
TOTAL	**100 marks**

Section

1 The Magnetic Field



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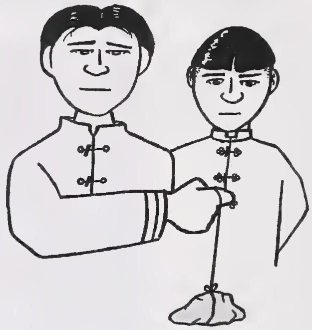
A compass is useful when it is used with a map because it can indicate directions and show the way to your destination. The tiny needle inside the compass is actually a small magnet that aligns itself with the north and south magnetic poles of Earth. Have you ever wondered how a compass needle is deflected even though nothing seems to be touching it?

In previous modules this kind of phenomenon was classified as action at a distance. The outcome of theories developed to explain these events is a field concept. The same approach will be used here.

In this section you will begin by identifying the significance of magnetism to past and present human societies. You will then investigate the magnetic fields created by bar magnets and moving charges. The observations from these investigations will become the basis for rules that will be referred to throughout the rest of the course. One application of these rules is solenoid technology, which you will explore by building and testing your own solenoids. The section ends with an opportunity to summarize all that you have learned.

Activity 1: Magnetism in a Human Context

The knowledge and use of magnetism goes far beyond the discovery of lodestone, a magnetic iron ore discovered by the Chinese over 2000 years ago. Chunks of lodestone were the first hand-held magnets that people could use.



1. Examine the drawing to the right. What use did lodestone have to society about 2000 years ago?

Some of your previous experiences should tell you that not all substances are magnetic. In this module you will examine why some substances are magnetic and others are not.

2. a. Name one substance that is magnetic.

   b. What do you think makes the substance magnetic?

Check your answers by turning to the Appendix, Section 1: Activity 1.

In Module 4 you studied electricity, the flow of charge. In this module you will discover that electricity and magnetism are closely related.

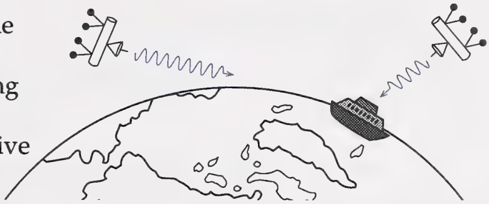
3. What is the basic energy transformation that occurs in the operation of an electric drill?

Many of the electric devices that you use involve conductors that carry a current that creates a magnetic effect. This magnetic effect interacts with other magnets and causes an energy transformation to occur. Did you know that magnetic particles on videocassettes and audiocassettes are aligned to produce video images and sound? Amazing! There are many more uses of magnetic effects than these basic energy transformations. You will discover that individual moving charges are also affected by magnets. For example, the systems of living organisms function by ion exchange. Therefore, magnetic effects could affect the operation of these systems.

4. What kind of research could be done with organisms living in environments where magnetic effects are particularly strong?

Fairly recent technological developments that use magnetism include electromagnetic impulse devices. These devices generate a changing magnetic field that is used to aid the healing process of injuries. Electromagnetic imaging devices, which provide an image of human tissue, have also been developed. This technology has been useful for imaging abnormal tissues, such as cancerous growths.

Navigation has also come a long way since the Chinese used a suspended piece of lodestone over 2000 years ago. Today, global positioning satellite systems (GPS) use electromagnetic waves generated by accelerating charges to give the precise location of objects on Earth.



5. a. Why is it important to study and understand concepts of magnetism?

   b. List four uses of magnetism.

Check your answers by turning to the Appendix, Section 1: Activity 1.

Magnetic effects play an important role in today's technological society. In the next activity you will investigate the magnetic effects due to a bar magnet.

Activity 2: Bar Magnets Create Magnetic Fields

In this activity you will have a first-hand opportunity to experience the properties of magnets.

Investigation: Properties of Bar Magnets

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will explore the regions of magnetic influence surrounding permanent bar magnets.

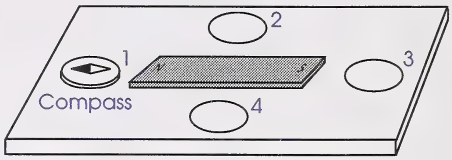
Materials

For this investigation you will need the following materials:

- two bar magnets
- a small magnetic compass
- iron filings
- a sheet of paper or a glass plate that measures approximately 20 cm × 28 cm

Procedure

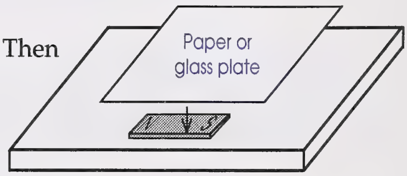
- Place the bar magnet on a flat surface.
- Bring the compass near the north pole, as shown by position 1 in the diagram. Observe the direction in which the north pole of the compass points.



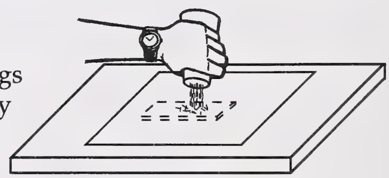
- Place the compass at positions 2, 3, and 4.

1. Copy the previous diagram into your notebook and indicate the direction in which the north pole of the compass points at positions 1, 2, 3, and 4.

- Place the bar magnet on a table or flat surface. Then place the paper or glass plate over the magnet.



- Gently sprinkle iron filings on the glass plate or paper. Be sure to work neatly because iron filings are difficult to remove from the magnet and they can permanently stain clothing.



2. Sketch the pattern of iron filings that you observe around the bar magnet.

magnetic field – the region surrounding a bar magnet in which a magnetic force exists

magnetic field lines – lines along which a magnetic force exists within a magnetic field

The alignment of the iron filings around the magnet can be described in terms of a **magnetic field**. The symbol for magnetic field is $\vec{B}$. The presence of the magnetic field around the magnet was shown with the iron filings. The distinct lines along which the iron filings align themselves are called **magnetic field lines**.

3. Do the field lines overlap? Support your answer by explaining your observations of the iron filings on the piece of paper.

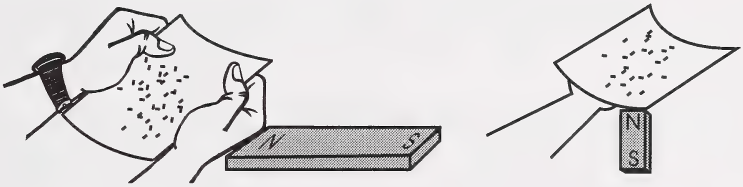
magnetic flux – density of magnetic field lines in a given space or area

The number of magnetic field lines passing through a given area is called **magnetic flux**. The magnetic flux per unit area is proportional to field strength.

4. Where is the magnetic flux the greatest around the bar magnet? Support your answer.

Caution

- Gently lift the paper off the bar magnet and slide the paper with iron filings onto the palm of your left hand. Be careful not to make a mess with the filings. Pick up the bar magnet with your right hand and place the north pole under the piece of paper. Observe the iron filings on the paper.

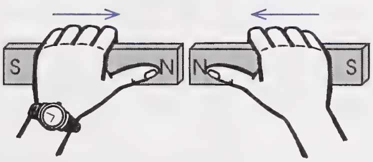


5. What happened when you placed the north pole of the magnet under the paper?

6. Does the magnetic field appear to be two-dimensional or three-dimensional? Support your answer with your observations.

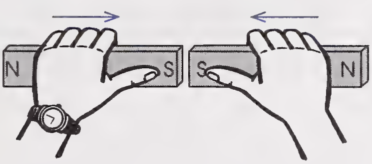
- Return the iron filings to the container.

- Hold one bar magnet in each hand and move the two north poles towards each other.



7. Describe the feeling when the two north poles are moved towards each other.

- Turn the magnets around and move the two south poles towards each other.

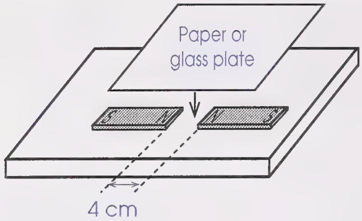


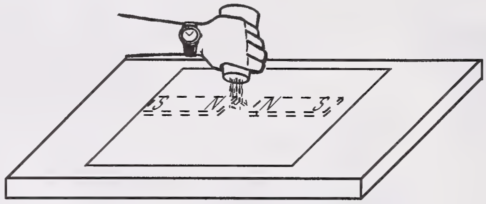
8. Describe the feeling when the two south poles are moved towards each other.

magnetic force – a force that exists within a magnetic field

Since the magnets can exert a **magnetic force** on each other without touching, there must be a field present.

- Place the two bar magnets on a flat surface with the north pole of one magnet about 4.0 cm from the north pole of the second magnet. Place the paper or glass plate over the magnets. Gently sprinkle iron filings on the glass plate or paper.

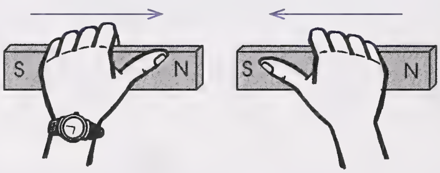




9. Sketch the pattern of iron filings between the ends of the bar magnets on a diagram in your notebook.

- Return the iron filings to the container. If you put a crease in the paper, you will be able to pour the filings in the container without spilling them.

- Hold one bar magnet in each hand and move the north pole of one magnet towards the south pole of the second magnet.



10. Describe the feeling when the north and south poles of these magnets are moved towards each other.

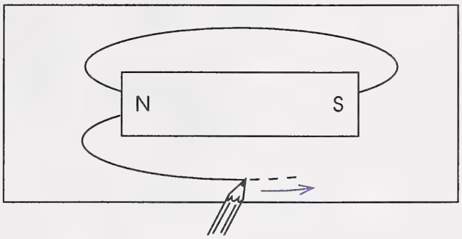
11. Describe the two types of magnetic forces that you have experienced.

- Place the north pole of one magnet about 4 cm from the south pole of a second magnet. Place a sheet of paper or glass over them. Sprinkle iron filings over the ends of the magnets.

12. Sketch the pattern of iron filings between the ends of the bar magnets and write a brief description of your observations.

- Trace the outline of one bar magnet in your notebook. Leave some space around it. Label the north and south poles of the magnet.

- Draw one arc above the outline of the magnet and one arc below it. These arcs should look similar to the patterns made by the iron filings.



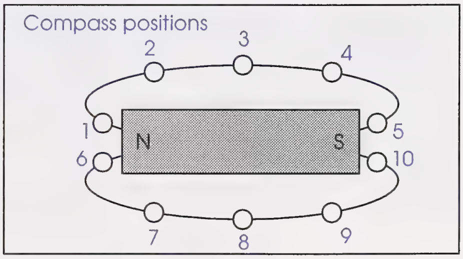
- Place the bar magnet over its traced outline.

Magnetic fields are vector fields much like gravitational and electric fields. The direction of a magnetic field is defined in terms of the direction of the north pole of a compass placed in a magnetic field.

- Place the compass near the north pole of the bar magnet. Note: The magnet should still be positioned over its outline in your notebook.

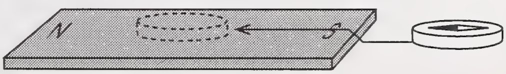
13. In which direction does the north pole of the compass point when placed near the north pole of the bar magnet?

- Slowly move the compass along the magnetic field line arc from position 1 to position 5. Then place the compass in position 6 and move it through to position 10.

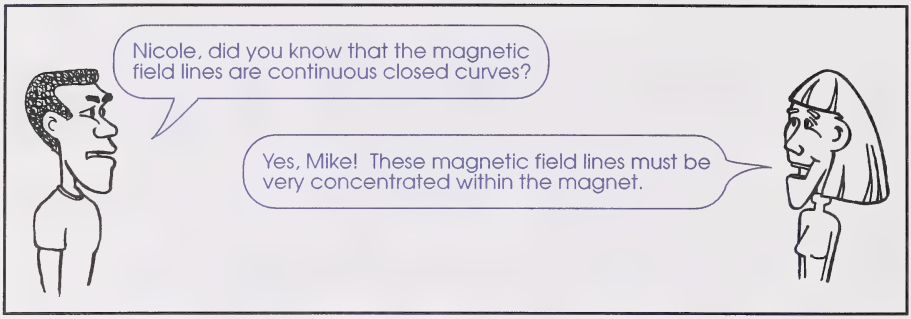


14. Sketch the direction of the magnetic field lines for positions 1 to 10. You can do this by drawing an arrow to indicate the direction of the north pole of the compass in each of these positions.

- Now place the compass near the south pole of the bar magnet. Slowly move the compass up over the south pole of the magnet and place it on the centre of the magnet.



15. Record the direction that the north pole of the compass points when placed on the centre of the magnet.



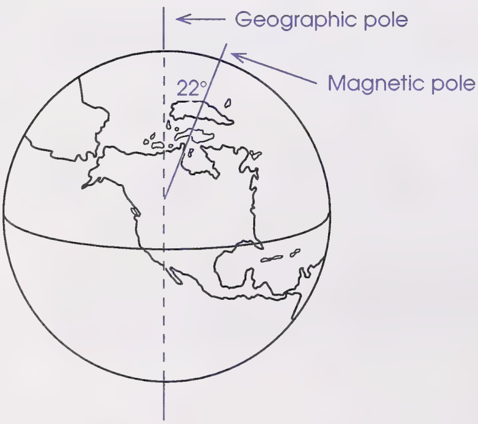
16. Draw a diagram that summarizes the directions of the magnetic field lines inside and outside a bar magnet.

Check your answers by turning to the Appendix, Section 1: Activity 2.

Conclusions

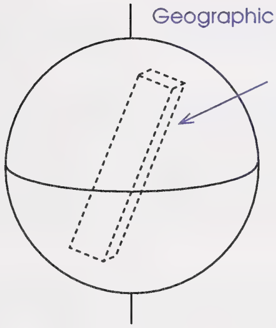
17. How does the alignment of the iron filings around the bar magnet compare with the alignment of the compass needle as the compass is moved around the magnet?

18. Is a net force acting on the compass needle when the compass needle is aligned along a field line? Provide evidence. Are there any forces acting on it?



The magnetic field surrounding Earth is similar to a magnetic field that surrounds a bar magnet. If you were orienteering in central Alberta, the north pole of your compass would align along a magnetic field line that is (on average) 22° east of the north geographic pole.

19. Copy the diagram to the right into your notebook and complete it by drawing in the field lines, labelling the direction of the field lines, and labelling the poles of the imaginary bar magnet inside Earth's magnetic field.



20. What is odd about the diagram that you drew to answer the previous question? When most people talk about the north pole, are they referring to the geographic north pole or the magnetic north pole?

You have now studied three kinds of fields: gravitational, electric, and magnetic. All of these fields can exert forces at some distance from the source. In the next activity you will discover that both electric and magnetic fields are generated by a charge.

21. Copy the following headings into your notebook. Be careful to adjust the space under each heading to accommodate your answers. Complete the chart by writing summary points comparing gravitational, electric, and magnetic fields.

Characteristic of Field	Gravitational	Electric	Magnetic
What is the source or origin of this field?			a moving charge
What determines the direction of this field?			
Can this field exert both attractive and repulsive forces?			
How does the force exerted by the field change as the distance from the source increases?			

Check your answers by turning to the Appendix, Section 1: Activity 2.

Activity 3: Moving Charges Create Magnetic Fields

In the last activity you analysed and plotted the magnetic field surrounding a permanent bar magnet. In this activity you will show the shape of magnetic fields and use hand rules to describe the magnetic fields surrounding current-carrying wires.

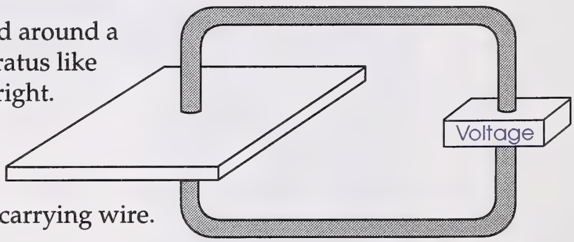
The video series called *Electromagnetism* contains a ten-minute program called *Magnetism and Electron Flow*. Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

1. How are two magnets similar to oppositely charged objects?

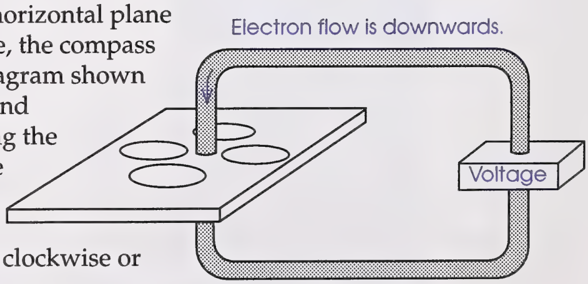
2. What did Hans Christian Oersted attempt to do through his experimentation using Volta's battery?

3. When Oersted placed a compass needle perpendicular to a conductor that was carrying electrons, there was no deflection. Describe the result when the compass needle was placed parallel to the conductor that was carrying electrons. What does this observation suggest about electricity and magnetism?

4. Ampere studied the magnetic field around a current-carrying wire using apparatus like that shown in the diagram to the right. Copy this diagram into your notebook and then complete the diagram by drawing the pattern of iron filings around the current-carrying wire.



5. When a compass is placed on a horizontal plane around the current-carrying wire, the compass needle is deflected. Copy the diagram shown to the right into your notebook and complete the diagram by drawing the direction in which the north pole of the compass points in each position. Indicate whether the direction of the magnetic field is clockwise or counterclockwise.

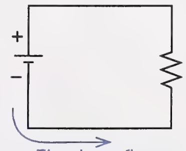


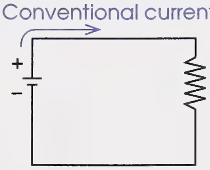
6. How does the shape and direction of the magnetic field change when the direction of electron flow is reversed?

Stop the video so that you can think about what you have just seen. The magnetic field lines that you've been dealing with circle a wire that has electrons flowing through it. These magnetic field lines have either a clockwise or counterclockwise direction, depending on the direction of electron flow. How can you remember which field direction matches which magnetic field circulation?

A convenient way to remember and predict field directions involves using your hands. You can use either your right or left hand, depending on how you describe the flow of charges. Remember that there are two ways to describe charge flow:

- **Electron flow** is the flow of negatively charged electrons from the negative terminal of a voltage supply to the positive terminal.





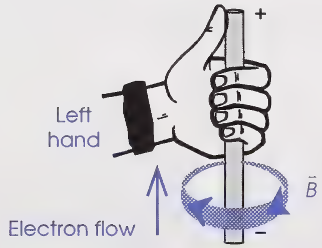
- **Conventional current flow** is the imaginary flow of positive charges from the positive terminal of a voltage supply to the negative terminal.

To determine the direction of the magnetic field around a current-carrying wire, you can use the left-hand rule for electron flow or the right-hand rule for conventional current flow.

left-hand rule for conductors – a rule that shows the direction of the magnetic field around a conductor using electron flow

Left-Hand Rule for Conductors

Place the thumb of your left hand so that it points in the direction of electron flow. Your fingers will now encircle the conductor and point in the direction of the magnetic field lines.

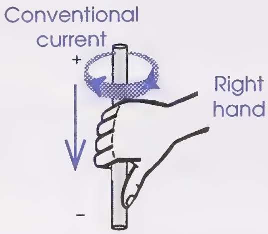


The magnetic field around the conductor is clockwise when viewed from the top.

right-hand rule for conductors – a rule that shows the direction of the magnetic field around a conductor using conventional current flow

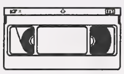
Right-Hand Rule for Conductors

Place the thumb of your right hand so that it points in the direction of conventional current flow. Your fingers will now encircle the conductor and point in the direction of the magnetic field.



The magnetic field around the conductor is clockwise when viewed from the top.

The correct use of either of the hand rules results in the same direction for the magnetic field. The important thing is to be consistent. Always use your left hand for electron flow and your right hand for conventional current.



Now you should be ready to return to the videocassette. Familiarize yourself with the remaining questions prior to watching the program. As you watch the tape, try using the hand rules to confirm directions whenever the rules are used on the screen. It is very important that you master the use of the hand rules, so if something doesn't work out, stop the tape, return to these explanations, and try again.

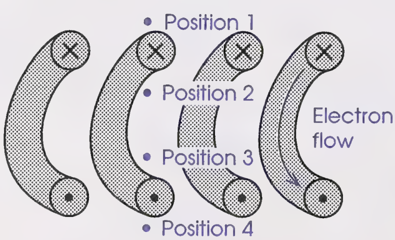
7. Use diagrams to illustrate that the reversal of current in a conductor results in the reversal in the direction of the magnetic field.

8. When current flows through a conductor, a magnetic field is set up around the conductor. Describe the result of opening a switch in a circuit in terms of $\vec{B}$.

9. When working with a helix (coil) that consists of a series of loops, the symbols ⊙ and ⊗ are used. What do these symbols represent?

electromagnet – a series of current-carrying coils that produces a magnetic field similar to a bar magnet

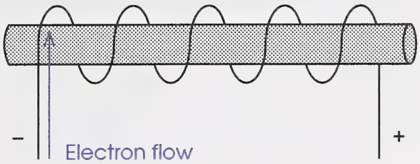
10. This diagram represents the side view of an **electromagnet** with electron flow through the coils. Copy this diagram into your notebook and use the appropriate hand rule to indicate the direction of the magnetic field at positions 1, 2, 3, and 4.



11. Briefly explain why the magnetic field strength is stronger inside the coils than outside.

left-hand rule for coils – a rule that shows the direction of the magnetic field inside a coil that is passing a flow of electrons

12. The **left-hand rule for coils** is used to predict the direction of the magnetic field produced by a coil or electromagnet. It states that the fingers point in the direction of the electron flow and the thumb points in the direction of the magnetic field **inside** the solenoid. Apply this rule to show the north and south poles of the electromagnet that is shown.



Stop the videocassette at the end of the program.

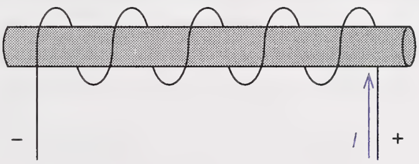
Check your answers by turning to the Appendix, Section 1: Activity 3.

Although the videotaped program dealt exclusively with electron flow, it is also correct to think in terms of conventional current. For example, the hand rule for the magnetic field around a conductor that is carrying moving charges has two versions – the left-hand rule for electron flow and the right-hand rule for conventional current.

right-hand rule for coils – a rule that shows the direction of the magnetic field inside a coil that is passing a conventional current

The **right-hand rule for coils** can also be used to show the direction of the magnetic field produced by a coil or electromagnet. The thumb still indicates the direction of the magnetic field inside the coil, but the fingers of the **right hand** curl around in the same direction as the flow of conventional current.

13. Apply the right-hand rule for coils to predict the north and south poles of the electromagnet that is shown.



14. Compare your answers to the previous two questions. Does it matter whether you think in terms of electron flow or conventional current? Explain concisely.

15. Copy the following headings into your notebook. Be careful to adjust the space under each heading to accommodate your answers. Complete the chart by indicating two similarities and two differences between permanent bar magnets and electromagnets.

Comparing Permanent Bar Magnets to Electromagnets	
Two Similarities	**Two Differences**

Check your answers by turning to the Appendix, Section 1: Activity 3.

Your textbook has some interesting diagrams and explanations that will help reinforce what you've been learning about magnetic fields and the hand rules.

Read pages 494 and 495 of your textbook and do the following questions.

16. Do Practice Problems 1 through 4 on page 496 of the textbook.

Check your answers by turning to page 683 of your textbook.

Read pages 496 to 498 to discover how the textbook treats the hand rules. The textbook uses the term *first right-hand rule* to refer to the right-hand rule for conductors. It uses the term *second right-hand rule* to refer to the right-hand rule for coils. Since the textbook refers only to the right hand, it is describing magnetism in terms of conventional current only. Keep these ideas in mind as you do the following questions.

17. Do Practice Problems 5 to 8 on page 499 of your textbook.

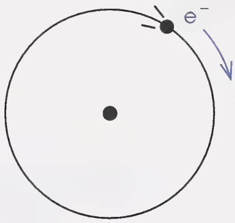
Check your answers by turning to page 683 of your textbook.

In the next part of this activity you will investigate magnetism at the atomic level.

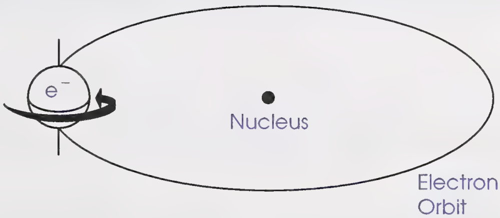
The video series called *Electromagnetism* contains a ten-minute program called *Domain Theory*. Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

18. Describe what happens when an iron core is inserted into the coils of an electromagnet.

19. The movement of electrons around the nucleus of an atom is similar to electron flow in a coil. Copy the diagram to the right into your notebook. Use the left-hand rule to indicate the direction of the north pole of the magnetic field in the diagram.



20. The electron spinning on its axis generates a second magnetic field. Copy the following diagram into your notebook. Use the left-hand rule to indicate the direction of the north pole of the magnetic field of the electron spinning on its axis.



21. Why are most materials not magnetic?

22. Why does iron display a net magnetic field?

23. Name the three ferromagnetic substances that display a net magnetic field.

24. The atoms of ferromagnetic substances are said to be magnetic dipoles consisting of two poles – a north pole and a south pole. What is an alternative way to describe the magnetic dipoles?

25. What is the name given to a cluster of dipoles that point in the same direction?

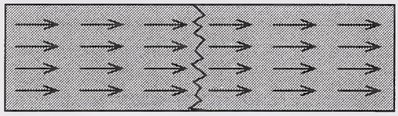
26. Explain why the magnetic field strength is increased when an iron bar is inserted into the coils of an electromagnet.

27. Describe the alignment of the domains of the iron bar within the core of the electromagnet when current no longer flows through the electromagnet.

domains – groups of neighbouring atoms that produce magnetic fields that align in the same direction

28. What substance is added to iron to prevent the **domains** from going in various directions?

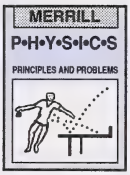
29. Copy the following diagram into your notebook. Imagine that this permanent bar magnet is broken. Indicate the poles on both pieces.



30. Name two ways of destroying a permanent bar magnet.

Stop the videocassette when the program ends.

Check your answers by turning to the Appendix, Section 1: Activity 3.



The textbook extends the domain concept to a variety of interesting applications. Read pages 499 and 500 of your textbook to find out more about these applications.

31. Explain how domains are used to record information on audiocassettes and floppy disks.

32. How have rocks on the ocean floor helped scientists track changes in the position of the earth's magnetic poles?

Check your answers by turning to the Appendix, Section 1: Activity 3.

So far you have learned about the properties of magnets by doing demonstrations with bar magnets and by watching video-taped programs with computer animation. The next stage in your study of magnetism will require you to build an important tool that will become an essential device for completing this module and Module 6.

Activity 4: Solenoid Technology

solenoid – a coil of wire that is used to generate or detect strong magnetic fields

A **solenoid** is simply a coil of wire wrapped around a core. The core can be a piece of iron or it can be hollow, in which case it is said to be an air core.

Solenoids are exceptionally useful in situations where a very intense magnetic field needs to be either generated or detected. For example, most electromagnets are iron-core solenoids. The starter in a car uses a large surge of current from the car's battery that flows through a solenoid to help start the car's engine.

One of the best ways to understand how a solenoid works is to build it and then test it yourself. This is what you will do in the next two investigations.

Investigation: Building Two Air-Core Solenoids

Science Skills

- ❑ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ❑ D. Analysing
- ❑ E. Synthesizing
- ❑ F. Evaluating

Purpose

In this investigation you will learn why the principles of magnetism apply so well to a solenoid by building two for yourself. You will also be providing yourself with two essential pieces of equipment for future investigations in this module and the next module.

Materials

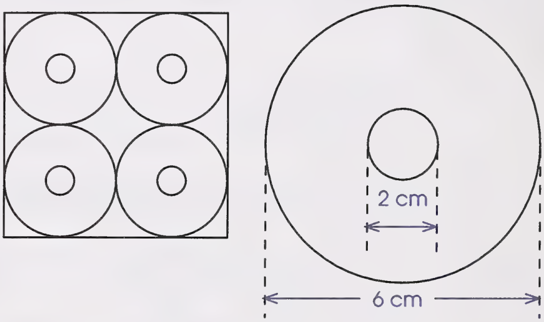
You will need the following materials for this investigation:

- two PVC terminal adaptors (TA10) with 0.5-inch inside diameters
- two PVC threaded plastic bushings for terminal adaptors with 0.5-inch inside diameters
- piece of stiff paper that measures $12\ \text{cm} \times 12\ \text{cm}$
- approximately 120 g (4 oz) of 28-guage, enamelled magnet wire
- two insulated alligator clips with screw-terminal connectors (one red, one black)
- a wire coat hanger
- a chair with an unupholstered back
- scissors
- Phillips size 2 screwdriver or flat screwdriver
- an old butter knife
- black electric tape

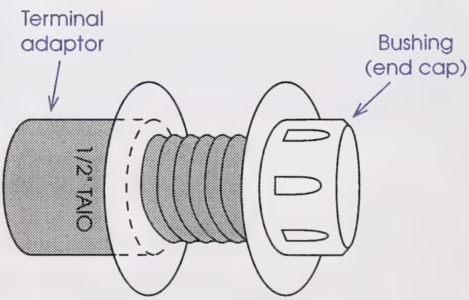
This photograph shows how a terminal adaptor, a bushing, and two rings cut from the stiff paper can be wrapped with the wire to produce a solenoid.

Procedure

- The procedure requires you to pay close attention to details. Read through the entire procedure before you begin to complete any of the individual steps.

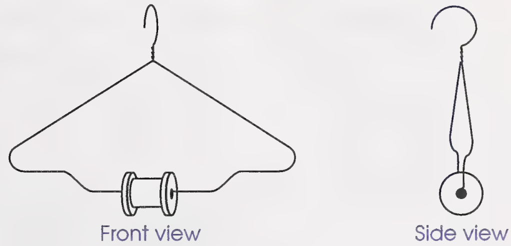


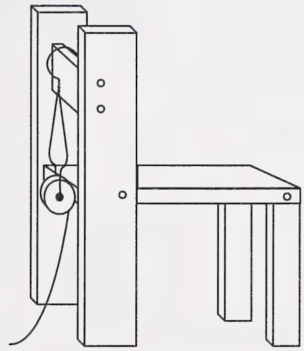
- Cut out four circles from the piece of stiff paper with scissors. The dimensions are shown.
- Put a small hole (2-cm diameter) in the middle of each circle.



- Carefully twist both pieces of paper onto the terminal adaptor and then tightly screw on the bushing (end cap). Adjust the pieces of paper so that they are as far apart as possible.
- Clear a path in a long room or hallway so that you can walk without bumping into anything. Place an unupholstered chair at one end of the room or hallway to hold the spool of magnet wire.

- Twist open a wire coat hanger and insert one end of the hanger through the spool of wire. Gently twist the coat hanger back together and shape it as shown.

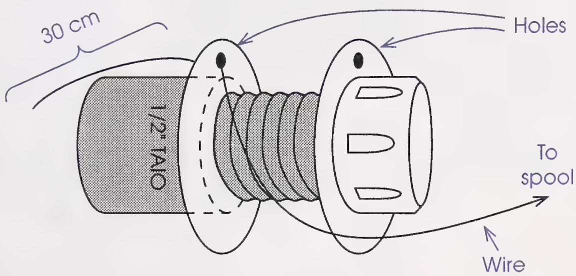




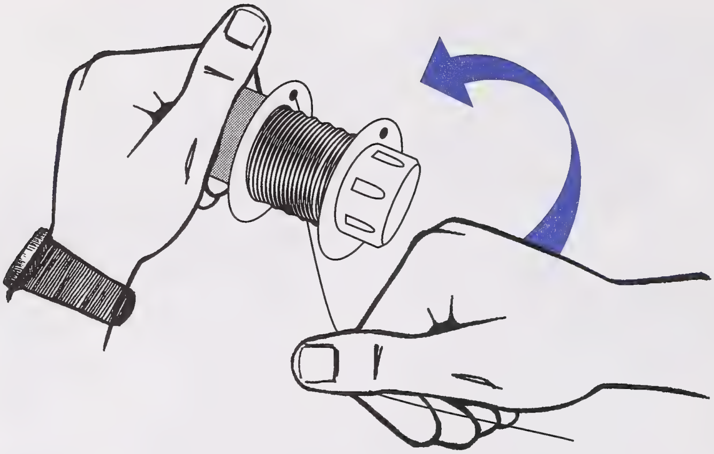
- Attach the coat hanger to the chair as shown. You may need to put a towel over the back of chair so that the coat hanger won't scratch it.

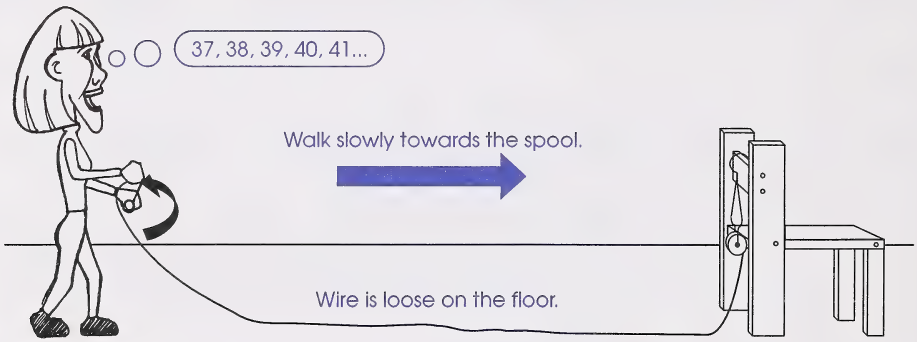
- Loosen the free end of the wire from the spool and walk backwards while holding the free end. The wire should easily flow off the spool without developing kinks or twists. If necessary, adjust the shape of the coat hanger to allow the spool to turn easily. You are now ready to wind the solenoid.

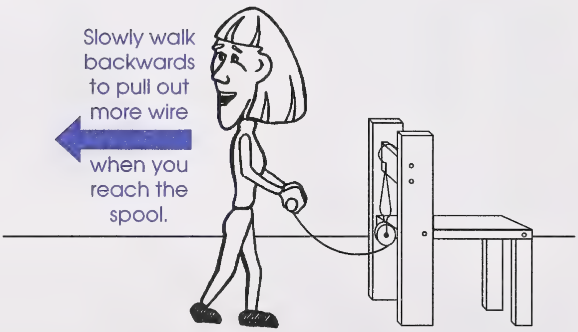
- Use a sharp, pointed object (a very sharp pencil) to make a tiny hole in the papers at each end of the solenoid. Feed the free end of the wire through the hole. Pull about 30 cm of wire through this hole.



- Hold the stem of the solenoid and the 30 cm of wire in one hand while you wrap the wire around the solenoid with the other. Count each turn of wire on the solenoid. As you wrap, slowly walk towards the spool. When you get to the spool, gently pull out more wire from the spool by **walking backwards**. It is important not to turn around because you will put kinks and twists into the wire. It seems that letting the wire sit loosely on the floor in front of you helps maintain the right amount of tension as you wrap. The diagrams on the following page illustrate the proper technique.





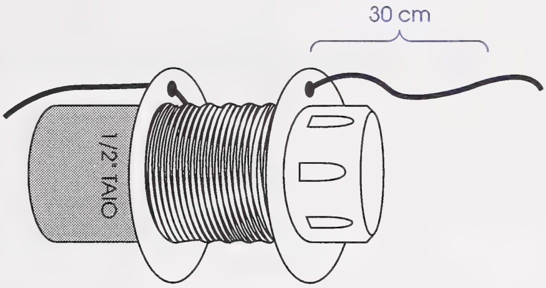


- Since you will put 800 turns on the solenoid, it will be easy for you to lose count. Keep track by making a mark in your notebook when you have made 100 turns. When you have eight marks in your notebook, you will know that you have 800 turns of wire on the solenoid.

- Try to put the turns of wire on evenly and with uniform tension.

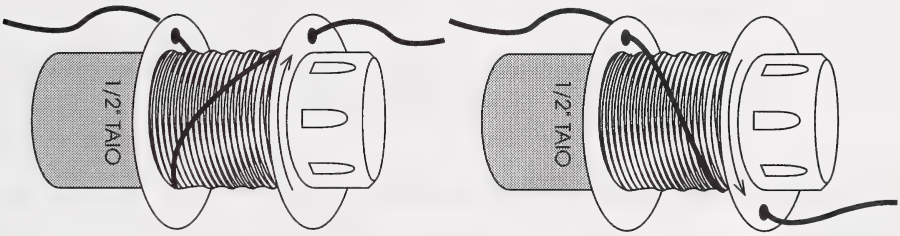
- If the wire gets kinked, carefully twist the solenoid in whatever direction is necessary to straighten it out.

- When you have put 800 turns on the solenoid, cut 30 cm of additional wire and put it through the paper at the other end of the spool, as shown in the diagram.

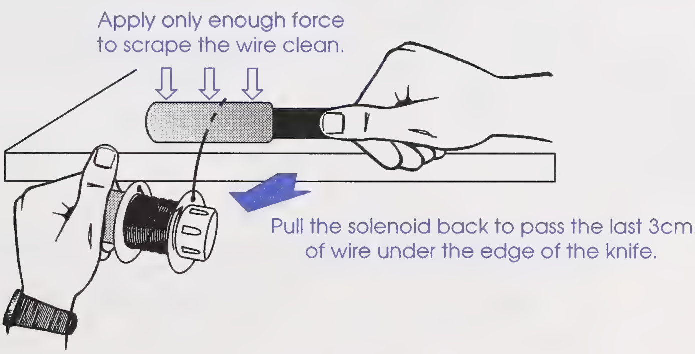


- Attach tape to the outside of the paper ends where the wire emerges so that the solenoid looks like the one shown at the beginning of the investigation.

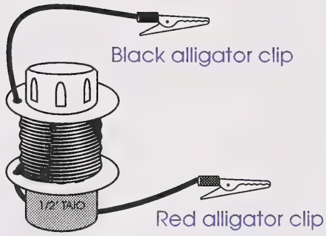
- Use a pen to label the paper ends of the solenoid as shown in the following diagram. The arrow records the way that you wound the solenoid and also the direction that the last bit of wire travelled before emerging. It is very important that the arrow matches the direction of the wire. You may find it helpful to loosen the last bit of wire to check the direction it travelled before emerging. The following diagrams show the two possibilities.



- Scrape the enamel off the last 3 cm of each piece of wire that leaves the solenoid. A good technique is to apply light downward pressure with a butter knife while pulling the wire out from between the knife and a table or flat surface.



- Attach each of the free pieces of wire to alligator clips. Feed the wire through the hollow plastic insulation, twist it around the screw, and then tighten the screw with a screwdriver so that the wire does not become unattached from the alligator clips.



  Attach a red alligator clip to the length of wire that first passed through the hole when you began winding. Attach the black alligator clip to the length of wire that came through the end near the bushing when you were finished winding.

- Repeat the procedure and make another solenoid with 400 turns instead of 800 turns.

- Label the number of turns of wire beside the arrow on each solenoid.

In the next investigation you will test the solenoids to see if they are working properly.

Investigation: Testing Two Air-Core Solenoids

Purpose

In this investigation you will construct a simple circuit using the two air-core solenoids that you constructed and then you will show the direction of the magnetic field surrounding the coils.

Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electric outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.

- Only replace the fuse inside the meter with the specified or approved equivalent fuse.

- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.

- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Materials

You will need the following materials for this investigation:

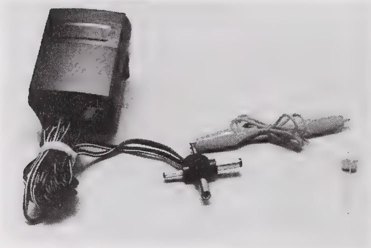
- two air-core solenoids
- a low-voltage power supply
- a 6.0-cm $\left(2\frac{1}{2}\text{-inch}\right)$ bolt
- a multimeter capable of measuring 0 V to 3 V and 0 mA to 250 mA. An equivalent voltmeter and ammeter could also be used.
- 30-Ω power resistor
- two electric leads (one black, one red) with alligator clips on each end
- compass

Procedure

- Read through the entire procedure before you begin to assemble the circuits.

- Before you begin constructing the circuit, it would be helpful to see what the end product will look like when assembled. Examine the photo carefully.

- Connect one end of an electric lead to the positive end of the low-voltage power supply and the other end to the 30 - Ω power resistor.



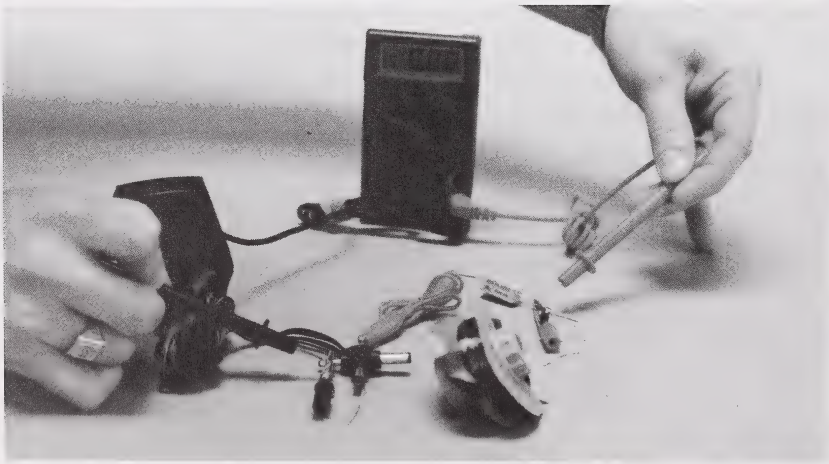
- Take the 400-turn air-core solenoid and attach the red alligator clip to the 30 - Ω power resistor.

- Attach one end of the other electric lead to the black alligator clip of the solenoid. Attach the other end to the negative terminal of the low-voltage power supply.

- Adjust the voltage supply to provide about 4.0 V to the circuit.

1. Sketch a schematic diagram of the circuit you just constructed.

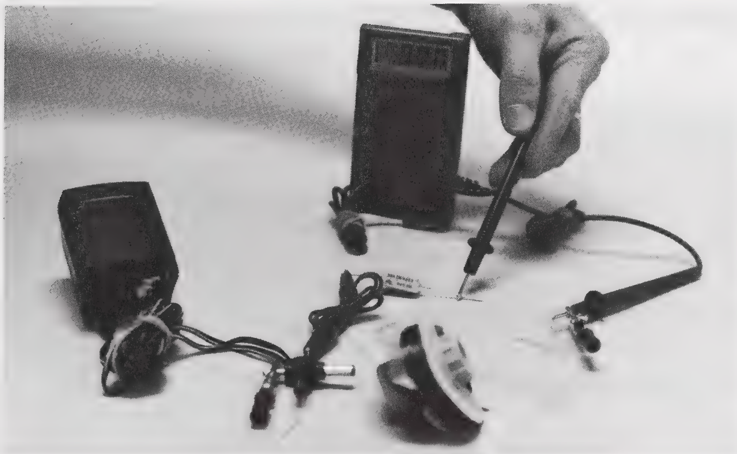
- Connect the multimeter in parallel across the air-core solenoid to measure the potential difference. Note the position of the positive and negative leads on the multimeter.



Caution

2. What is the voltage reading across the air-core solenoid? Do not leave the circuit connected for long periods of time because heat will build up within the solenoid and the power resistor.

   - After you have recorded the voltage, connect the multimeter in series and measure the current in the circuit. Remember to readjust the dial the position of the leads to measure current.

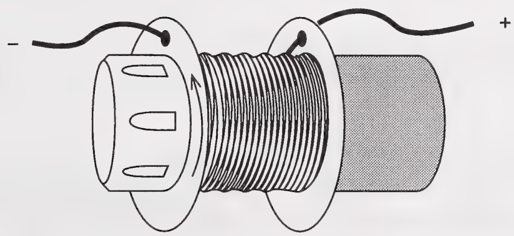


Note: If you get a negative reading for current, simply reverse the connections to the leads. If you get a reading for voltage, but no reading for current, check the fuse in the back of the multimeter. If the fuse is blown, replace it with the fuse that is supplied.

3. Record the current (in amperes) in the circuit. Disconnect the multimeter from the circuit.

4. Calculate the resistance of the 400-turn air-core solenoid.

   - Reconnect the alligator clips to complete the circuit. Note the direction in which the wire is coiled on the solenoid and the direction of conventional current flow through the coils. It should be the same!



5. Use the appropriate hand rule for a solenoid to determine which end of the air core corresponds to the north end.

   - Place a compass at the end of the solenoid that you have predicted to be the north end.

6. Compare the direction of the magnetic field predicted by the hand rule and the direction in which the north pole of the compass points.

   - Move the compass in an arc, from one end of the air core to the other, about 10 cm from the solenoid.

7. Describe the shape of the magnetic field surrounding the solenoid.

   - Place the 6.0-cm bolt into the centre of the solenoid and move the compass in the same arc about 10 cm from the solenoid.

8. Describe the difference in magnetic field strength when the bolt is inserted into the centre of the solenoid.

   - Repeat the entire procedure using the 800-turn solenoid.

9. Record the voltage reading across the 800-turn solenoid.

10. Record the current (in amperes) in the circuit with the 800-turn solenoid.

11. Calculate the resistance of the 800-turn solenoid.

12. Explain why there is a difference in resistance between the two solenoids.

13. How does the magnetic field strength of the 800-turn solenoid compare with the magnetic field strength of the 400-turn solenoid? You may wish to move the compass away from each of the solenoids in the circuit and compare the compass deflections.

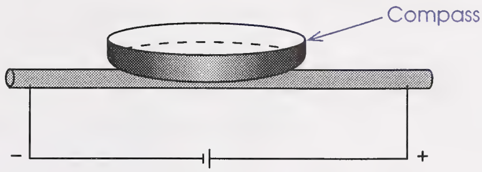
Check your answers by turning to the Appendix, Section 1: Activity 4.

In the next activity you will apply the hand rules of magnetism to a variety of situations.

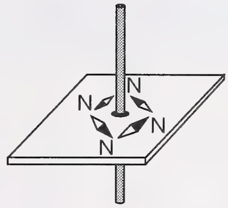
Activity 5: Wrap-up

The videotaped programs that you watched earlier in the module developed two hand rules that can be used to determine the direction of the magnetic field when charge moves through a conductor. In this activity you will apply these hand rules in a variety of situations to highlight the key ideas from this section.

1. Indicate the direction in which the north pole of a compass would point when placed above the current-carrying wire shown in the diagram.

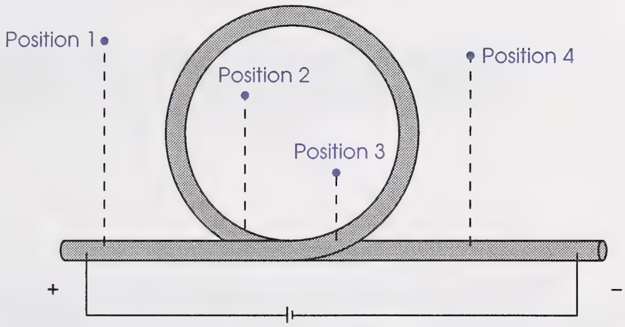


2. When a compass is placed at various positions around a wire positioned in the vertical plane, the north pole of the compass points counterclockwise when viewed from above. What is the direction of conventional current flow in the conductor?

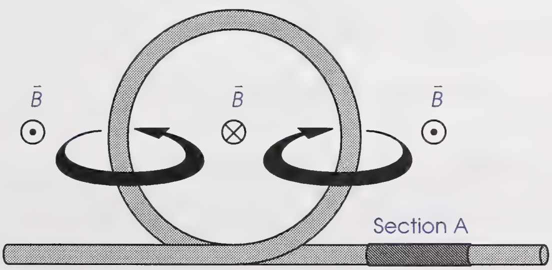


3. A conductor is carrying a conventional current directly towards you. Draw a diagram that illustrates whether the magnetic field around the conductor is clockwise or counterclockwise.

4. Current is flowing through a single loop of wire, as indicated in the following diagram. Identify the direction in which the north pole of a compass would point at positions 1, 2, 3, and 4.

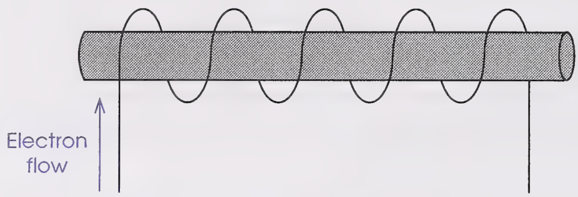


5. The magnetic lines of force around a single loop of wire are illustrated in the following diagram. Determine the direction of electron flow through the wire in section A.



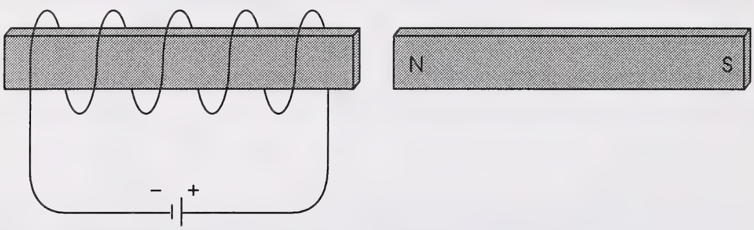
6. A coil of copper wire is positioned on its vertical axis so that conventional current through the coils is clockwise when viewed from above. Is the north pole of the coil at the top or the bottom of the coil?

7. The following diagram shows a coil wrapped around an iron core. Determine the direction in which the domains would align within the iron core and determine which end of the core would be the north pole.



8. Two electrons that are adjacent to each other are spinning on vertical axes in a counterclockwise direction when viewed from above. Draw a diagram and sketch two external lines of magnetic force around each of the electrons to indicate why the magnetic fields would enhance each other.

9. Copy the following electromagnet and bar magnet into your notebook. Sketch the lines of force between the ends of the magnets.



Check your answers by turning to the Appendix, Section 1: Activity 5.

Follow-up Activities

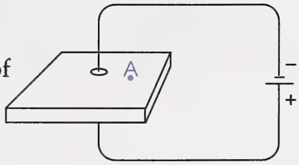
If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. Copy the following headings into your notebook. Leave enough space under each heading for your answers. Complete the chart by filling in summary points for bar magnets.

Summary Chart for Bar Magnets	
Direction of $\vec{B}$ Outside Bar Magnet	
Direction of $\vec{B}$ Inside Bar Magnet	
Region(s) Where $\vec{B}$ Is Most Concentrated	
Kind of Force(s) Between Magnets	

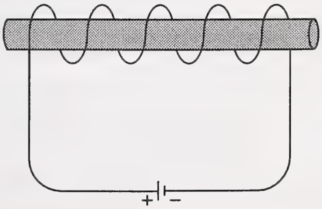
2. Use the appropriate hand rule to determine the direction of the magnetic field at point A in the diagram.



3. Sketch the alignment of domains in magnetized and unmagnetized iron.

4. Indicate three ways that you could increase the magnetic field surrounding a solenoid.

5. Copy the diagram into your notebook. Use the appropriate hand rules to label the north and south poles of the electromagnet.



Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of the following activities.

1. Earth's Magnetic Field

The video series called *Electromagnetism* contains a ten-minute program called *Earth's Magnetic Field*. Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

a. When a piece of lodestone was suspended in the centre, what was the result and what advancements were made using this new form of navigation?

b. French scientist Pedros Peregritris chiselled a piece of lodestone into a sphere and then sprinkled iron filings around it. How did the iron filings align on the sphere?

c. Compare the arrangement of iron filings around a bar magnet here on Earth and the iron filing pattern around a bar magnet in space. Explain the difference in the patterns.

d. William Gilbert concluded that Earth is a huge bar magnet. On what basis did he conclude that the south magnetic pole is in the northern hemisphere?

e. Describe the result of heating a bar magnet.

f. What is believed to be the source of Earth's magnetic field?

g. Define the term *magnetic declination* that is mentioned in the video.

h. What is the magnetic declination in Toronto?

i. The magnetic field for a particular location is oriented with respect to Earth's surface. At what point on Earth's surface would the magnetic field line be parallel to Earth's surface?

j. What is the term given to the angle between Earth's surface and the field lines when the field lines cross the surface?

k. Describe the use of a dip needle. How would it be positioned over the north magnetic pole?

l. Explain why compass navigation in the Arctic would not be very accurate. Suggest other means of navigation.

2. Library Research

   If you have access to a library facility, write a paragraph on Hans Christian Oersted. Include where he studied, his scientific discoveries, and other interesting facts.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you have seen how helpful the concept of a field can be for explaining physical phenomena. The magnetic field is similar to the gravitational field and the electric field in many ways. However, one significant difference lies in the use of hand rules to predict directions. This makes the magnetic field quite different from what you learned in your previous work in the course.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 The Magnetic Force

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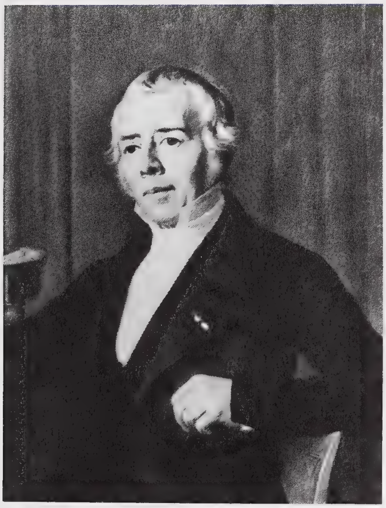
Is the magnetic force significant to your life? If the only example that you can think of is like the one shown in the photograph, the magnetic force may not seem too important. However, the applications extend far beyond electromagnets. Any device that has an electric motor utilizes the magnetic force. Likewise, any machine that has a video monitor uses the magnetic force to control an electron beam. This includes computer monitors and televisions. So, the magnetic force probably does have a significant impact on your life.

In this section you will trace the history of the discovery of the magnetic force and you will learn to describe this force in terms of a new hand rule. You will use this new hand rule in an investigation that will allow you to link many of the key ideas from this module. By the end of this section you should be able to apply what you have learned to explain the operation of a number of different devices.

Activity 1: Discovering the Magnetic Force



Hans Christian Oersted THE BETTMANN ARCHIVE

Hans Christian Oersted developed an interest in chemistry and physics while working in his father's pharmacy. He studied at the University of Copenhagen and followed the teachings of natural philosophy.

Oersted discovered a connection between electricity and magnetism in the early 1800s.

1. Briefly describe Oersted's important discovery about electricity and magnetism.

After Oersted's discovery, scientists wondered if magnets could influence currents the same way that currents affected magnets. The answer to this question was answered in a series of experiments conducted by Ampere only one year after Oersted's discovery.

The video series *Electromagnetism* contains a ten-minute program called *The Motor Principle*. Familiarize yourself with the following questions prior to watching the program. This will help you to focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers. You should also practise the hand rule by holding up your hand to the TV screen to be sure that you understand how this new rule works.

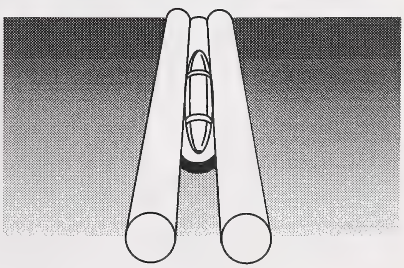
2. This diagram shows a device that could be used to launch projectiles.

   a. What is this device called?

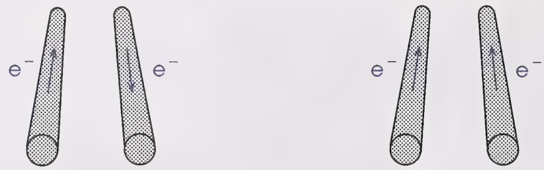
   b. What must occur within the rails for this device to work?

   c. Is the projectile an insulator or conductor?

   d. Why must the rails be securely anchored to the ground?



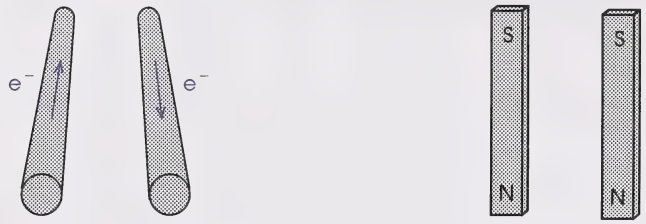
3. In 1820 Ampere made a discovery about two parallel wires when they each carry a flow of electrons.



   a. What happens to the wires when the electrons flow in the same direction in both wires?

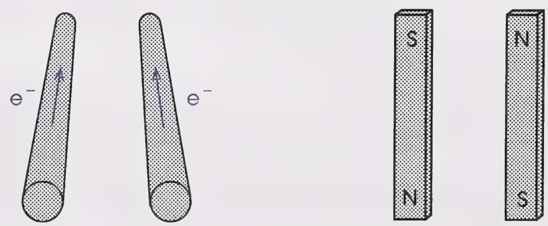
   b. What happens to the wires when the electrons flow in opposite directions in the wires?

   c. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams in your notebook by drawing the pattern of magnetic field lines for each.



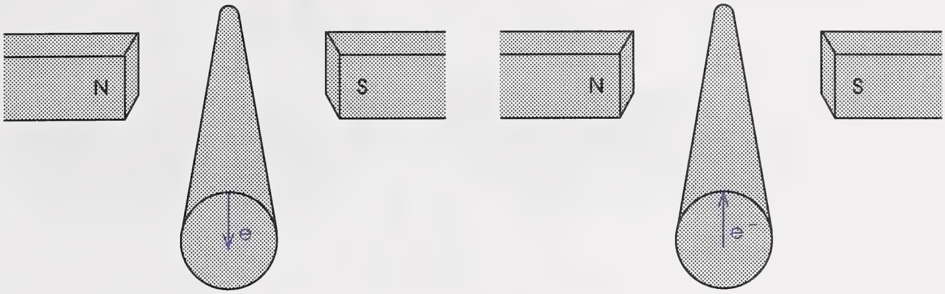
   d. Describe the similarity between the patterns of field lines on the diagrams you just drew. What do the field lines suggest about the forces in each case?

   e. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams in your notebook by drawing the pattern of magnetic field lines for each.

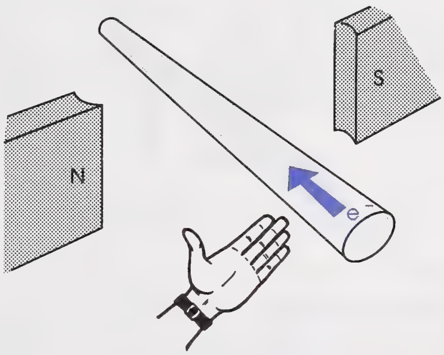


   f. Describe the similarity between the patterns of field lines on the diagrams you just drew. What do the field lines suggest about the forces for each?

4. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams in your notebook by drawing the patterns of magnetic field lines and the direction of the magnetic force in each.



5. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by drawing arrows and writing labels for the magnetic field $\left(\vec{B}\right)$ and the magnetic force $\left(\vec{F}_m\right)$.



motor principle – A magnetic force is exerted on a current-carrying wire that is placed at right angles to a magnetic field.

6. Why is this hand rule often referred to as the **motor principle**?

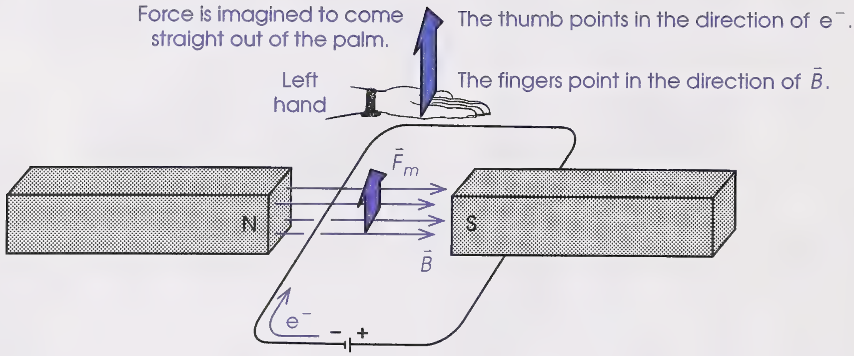
Stop the videocassette when the program ends.

Check your answers by turning to the Appendix, Section 2: Activity 1.

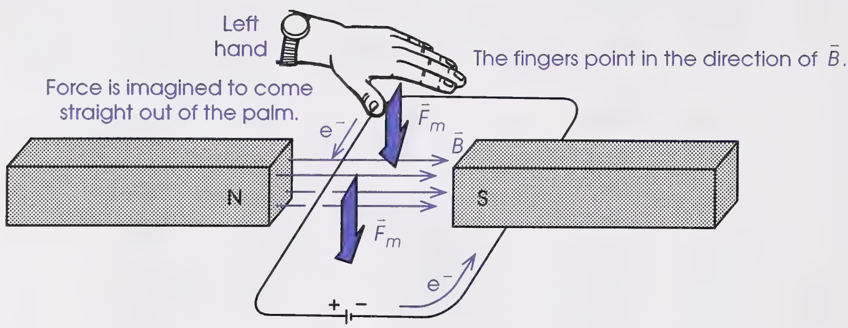
left-hand rule for force – a rule that shows the direction of the magnetic force acting on negative charges moving perpendicularly through a magnetic field

Ampere's discovery that magnets can exert forces on wires that are carrying a flow of electrons provides another example of a phenomenon that requires a hand rule to describe the directions involved. Unlike the hand rule for conductors and the hand rule for coils, this one requires your fingers to be held flat instead of curled. The following examples illustrate how the **left-hand rule for force** would be properly applied.

Example 1



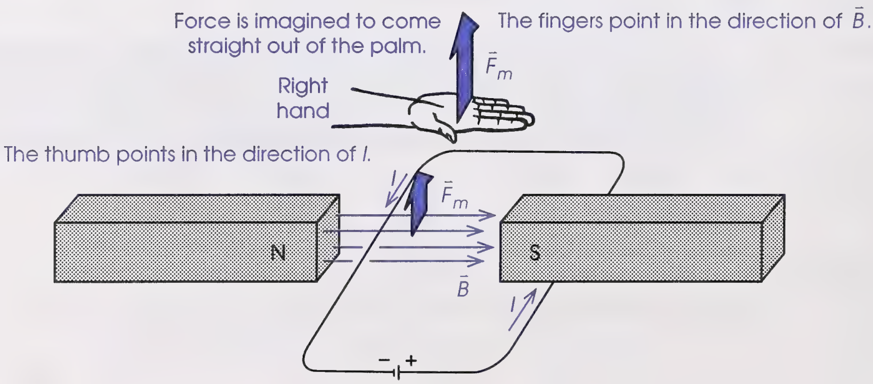
Example 2



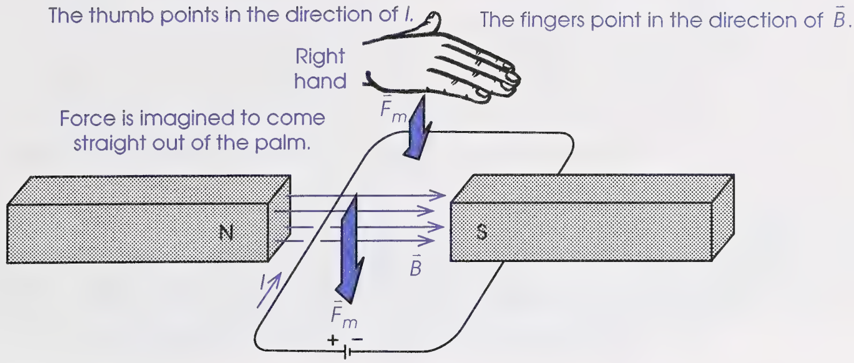
It is important to note that this hand rule forces you to keep $\vec{B}$, $\vec{F}_m$, and the direction of electron flow perpendicular to each other. Despite some of the differences, this hand rule does have one thing in common with the other two – it also has a right-hand version, the **right-hand rule for force**. This is illustrated in the following two examples.

right-hand rule for force a rule that shows the direction of the magnetic force acting on positive charges moving perpendicularly through a magnetic field

Example 3



Example 4



7. Carefully compare the circuit arrangements for Example 1 and Example 3.

   a. Is there any difference in the circuits?

   b. Is there any difference in the direction of the magnetic force?

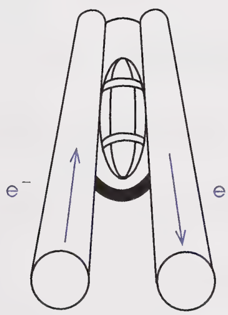
   c. Does it matter whether you think in terms of conventional current or in terms of electron flow?

   d. What is it important to do when you are applying these hand rules?

8. Explain why Example 2 and Example 4 produce the same direction for the magnetic force on the wire.

Although the videotaped program that you just watched had very helpful computer graphics, it did not provide a really clear explanation of how a rail gun works. Now that you know the hand rules for force, you can put together a better explanation.

9. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by drawing and labelling the magnetic field lines between the rails.



10. The projectile itself is a conductor which conducts the flow of electrons from the left rail to the right rail. Add this to your diagram.

11. You should now be able to determine the direction of the magnetic force on the projectile by using a hand rule. Remember the following key ideas as you determine the direction of the magnetic force:

    - The flow of electrons is from left to right through the projectile.
    - The magnetic field is directed vertically up through the projectile.

Check your answers by turning to the Appendix, Section 2: Activity 1.

So far the discussion of magnetic force has only involved direction. An equation that predicts the magnitude of this force does exist. This equation can be written as follows:

The current flowing through the wire

The length of the wires

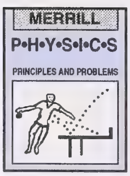
$$\boxed{F_m = I\ell B_\perp}$$

The perpendicular symbol reminds you that the magnetic field acts at a right angle to ℓ, I, and F_m.

The *m* indicates that this is a **magnetic** force.

This equation can also be written in vector notation.

$$\boxed{\vec{F}_m = I\ell B_\perp \text{, with direction determined by the hand rule for force}}$$



You can learn more about the origins of this equation by reading from the top of page 502 to the end of the first paragraph on page 504 of your textbook. You should keep in mind that the textbook refers to the right-hand rule for force as the *third right-hand rule*. The textbook deals only with conventional current and the notation for the equation is slightly different than what is presented in this module.

12. The unit for the magnitude of the magnetic field is the tesla, named after Nikola Tesla.

    a. What is the tesla equivalent to in terms of other units?

b. Use unit analysis to show that $1\ T = 1\ kg/C \bullet s$.

c. What is an average value for Earth's magnetic field strength?

13. The textbook suggests a unique way to remember that the symbol ⊙ represents a vector directed straight out of the page and the symbol ⊗ represents a vector directed straight into the page. What is this method?

Check your answers by turning to the Appendix, Section 2: Activity 1.

As with other parts of the course, it is important that you use the equations as they are shown in the Physics 30 data sheets and that you are careful with vector notation. The following question will allow you to practise these ideas.

14. A current-carrying wire passes a conventional current of 6.75 A horizontally from east to west. The wire has a 97.5-cm segment that passes through a magnetic field of 0.375 T that is directed to the north.

    a. Sketch a top view of the variables in this problem. Be sure to include an indication of north, south, east, and west.

    b. Calculate the magnitude of the magnetic force acting on the wire.

    c. Determine the direction of the magnetic force acting on the wire.

    d. Combine your answers from the previous parts of the question to state the magnitude and the direction of the magnetic force on the wire.

Now consider a question that is similar to the previous one, but think in terms of electron flow.

15. A wire that is 65.0 cm long and is positioned in the vertical plane has an electron flow of 0.755 A passing downwards through it. The wire passes through a magnetic field of 2.80×10^{-2} T that is directed east.

    a. Sketch a side view of the variables in this problem. Be sure to include an indication of north, south, east, and west.

    b. Calculate the magnitude of the magnetic force acting on the wire.

    c. Use the left-hand rule for force to determine the direction of the magnetic force acting on the wire. Check your answer by using the right-hand rule for force.

d. Combine your answers from the previous parts of the question to state the magnitude and the direction of the magnetic force on the wire.

Check your answers by turning to the Appendix, Section 2: Activity 1.

You will have more opportunities to practise predicting the direction of magnetic forces in the next activity. At this point it would probably be a good idea to focus on becoming familiar with units and the calculations of magnitude.

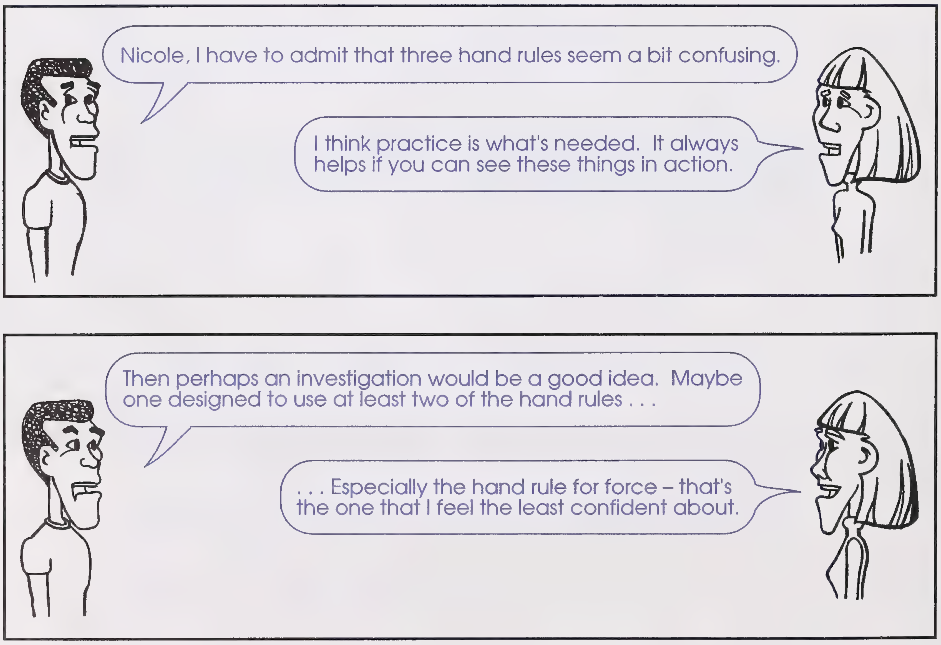
The following questions from the textbook will give you a chance to develop these skills.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

16. Do Practice Problems 9, 10, 11, and 12 on pages 504 and 505 of your textbook.

Check your answers by turning to page 683 of your textbook.

Activity 2: Investigating the Magnetic Force



Investigation: The Current Balance

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Part A

Science Skills
- ❐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ❐ F. Evaluating

Purpose

It is the purpose of this investigation to quantitatively determine the force on a conductor in a magnetic field.

Important Safety Precautions

Caution

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electric outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Only replace the fuse inside the meter with the specified or approved equivalent fuse.
- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

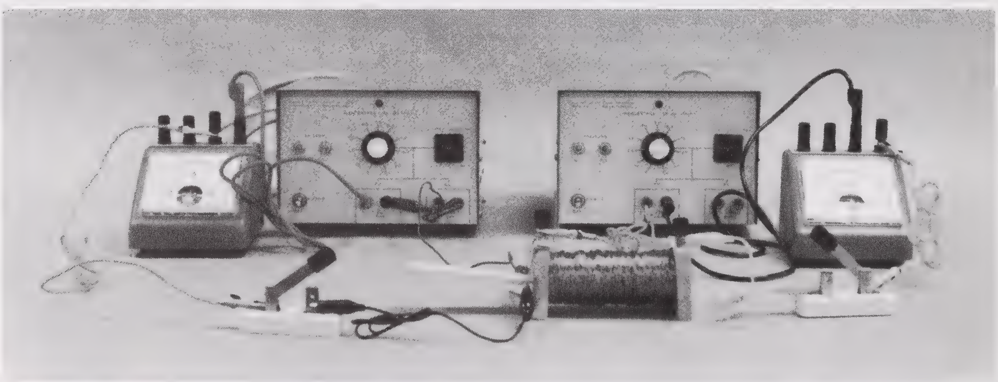
You will ensure your own safety by applying this information as you complete the investigation.

Materials

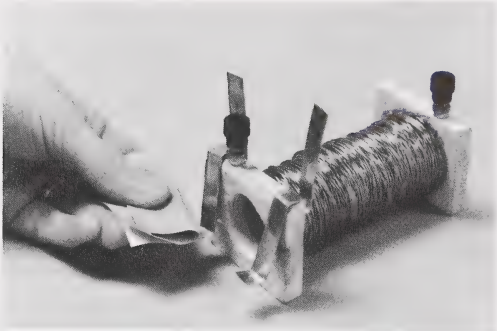
- air-core solenoid (10 cm by 3 cm)
- current balance attachment for the solenoid
- two ammeters (0 A to 5 A)
- two variable DC power supplies (0 V to 6 V)
- scissors
- connecting wires with alligator clips
- fine sandpaper (200 to 400 grit)
- 25 to 30 cm of cotton string used for tying parcels (approximately 0.80-mm diameter)
- two knife switches
- centimetre ruler
- electronic balance

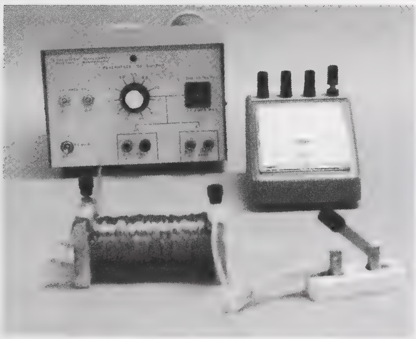
Procedure

You will be constructing two circuits, one with a solenoid and the other with the current balance. Before you begin, examine the following diagram to see what the two circuits will look like.



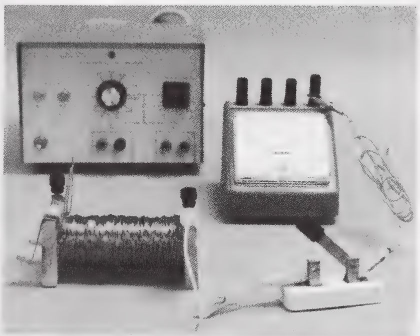
- You will begin to set up the apparatus by building the solenoid circuit. Use the fine sandpaper to clean the current balance supports on the solenoid.

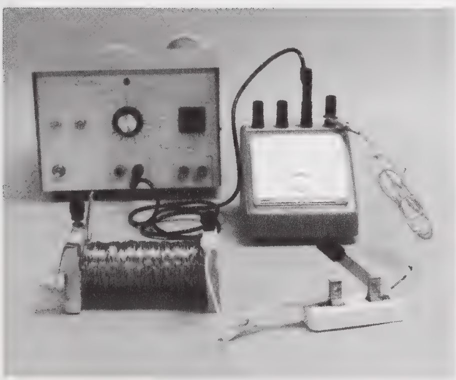




- Use connecting wires to attach the solenoid to the knife switch.

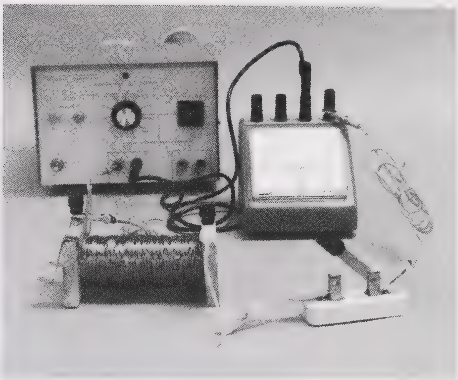
- Use a second connecting wire to attach the ammeter to the knife switch. Keep the knife switch open.





- Use a connecting wire to attach the second terminal of the ammeter to the positive terminal of the DC power supply.

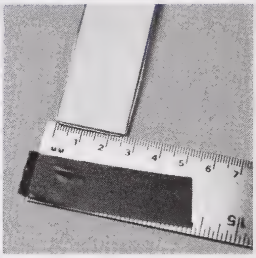
- Now use another connecting wire to connect the negative terminal of the power supply to the opposite end of the solenoid.



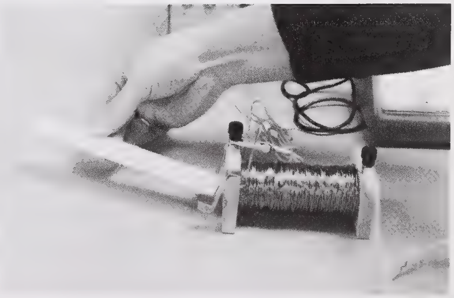
1. Draw a schematic diagram of the solenoid circuit and label the components.

Check your answers by turning to the Appendix, Section 2: Activity 2.

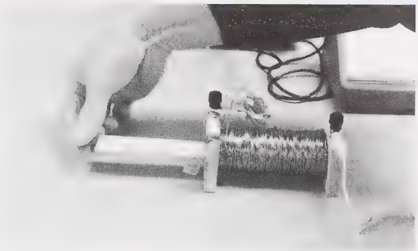
2. Before you construct the second circuit with the current balance loop, measure the length of wire across the end of the loop and record this value.



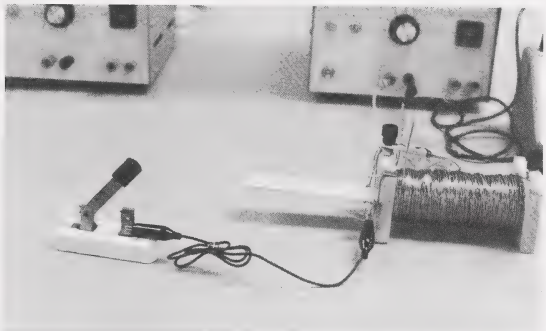
- Place the current balance loop with the wire into the centre of the solenoid.



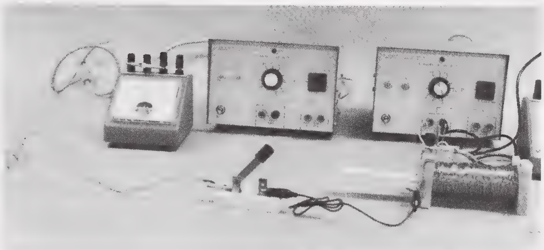
- Balance the current balance by adjusting the nut or pin at the end of the balance until the entire loop is horizontal.



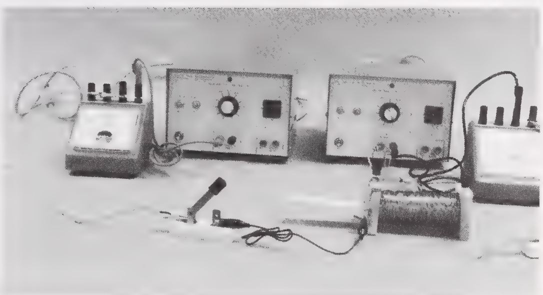
- Attach one end of a connecting wire to the current balance support and the other end to the knife switch. Keep the knife switch open.

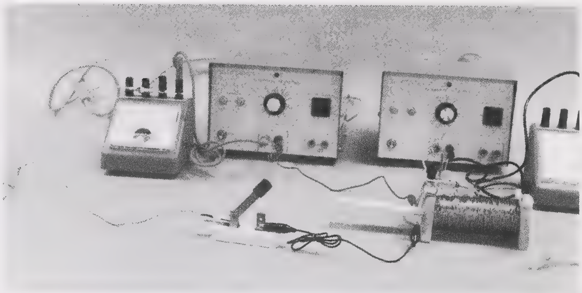


- Use a second connecting wire to attach the knife switch to the negative terminal of the ammeter.



- Use a connecting wire to attach the positive terminal of the ammeter to the positive terminal of the second DC power supply.



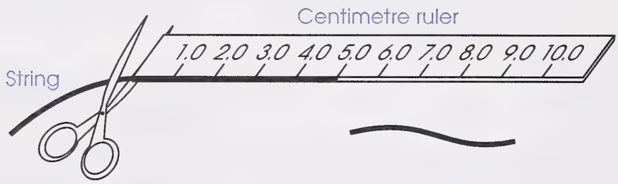


- Connect the negative terminal of the power supply to the opposite side of the current balance support on the solenoid.

3. Use the symbol  to represent a current balance loop in a schematic diagram of this circuit. Label the components.

- Before you proceed any further, make a final inspection of the wiring to be certain that the circuits are connected properly. Have the person who supervises the lab check your circuit.

- Take the string and cut it into 5.0-cm lengths. You will need five pieces.



- Copy the following headings into your notebook. Leave enough space under the headings to record data for five trials. Record the length of wire for the current balance loop. A completed chart will be included in the Appendix for your reference.

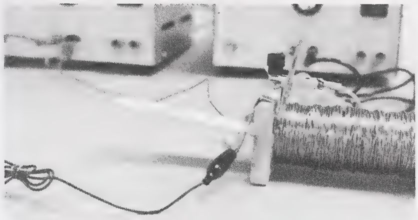
Trial	Length of Wire (m)	Current in Wire (A)	Current in Solenoid (A)	Mass of String $(\times 10^{-5}\ \text{kg})$	Force $(\times 10^{-4}\ \text{N})$	Magnetic Induction $(\times 10^{-2}\ \text{N/A}\bullet\text{m})$

- Close the knife switch that controls the current in the current balance.

- Adjust the output of the power supply until the current passing through the current balance loop is 1.0 A.

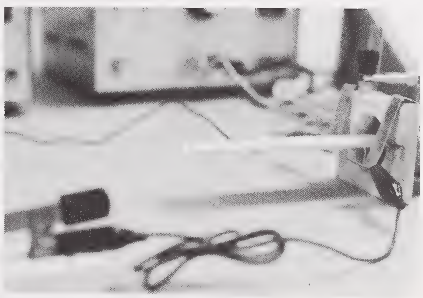
- Record the current in the loop in the data chart. The current through the loop will be constant for this investigation, so you should not change the power supply setting for the loop circuit for the remainder of the investigation.

- Close the knife switch that controls the current in the solenoid.
- Adjust the setting on the power supply for the solenoid circuit until about 4.0 A flows through it.
- The balance should be deflected upwards outside the solenoid due to the downward magnetic force on the end of the loop inside the solenoid.



- If the current balance is deflected downwards, turn off the power supply and **reverse** the two connections to the current balance.
- Turn off the current to the solenoid circuit and the loop circuit by opening both knife switches.
- Determine the mass of a 5.0-cm piece of string by placing it on an electronic balance.

- Record the mass of the string in kg on the data chart.
- Hang the piece of string on the adjusting nut on the end of the current balance.



4. What happens to the current balance when the string is placed on the adjusting nut?

- Turn on the current balance current by closing the knife switch. The ammeter should read 1.0 A.
- Turn on the solenoid current by closing the knife switch and slowly increase the current by using the adjustment on the power supply.
- When the current balance is level or balanced, the downward gravitational force due to the string on one side is balanced with the downward magnetic force on the end of the loop on the other side.
- Observe the current balance from a variety of positions to make sure that it is horizontal and balanced.
- Record the solenoid current on the data chart.
- Turn off the current to the solenoid circuit and the loop circuit by opening both knife switches.
- Determine the mass of two pieces of string.
- Hang two pieces of string on the current balance and repeat the balancing process to obtain the solenoid current that produces a horizontal current balance loop.
- Record the mass of the string and the solenoid current in the data chart.
- Repeat the procedure using three, four, and five pieces of string.

Caution

- Record the data for trials 3 through 5 on the data chart. Do not keep the solenoid current above 4.0 A for any length of time, as the coil will overheat. When you are finished collecting the data, open each knife switch and unplug each power supply.
- Continue with the Analysis section of this investigation that follows Part B.

End of Part A

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

Part B

Read the procedure for Part A so that you will have a thorough understanding of how the data was obtained for Part B. It is crucial that you read each step carefully and visualize how the apparatus would react in each case.

Copy the headings shown on the following page into your notebook. Some of the data has been provided for you and you should enter these values into the chart in your notebook. You will fill in the rest of the chart as you complete the Analysis. A completed data chart will be included in the Appendix for your reference.

Trial	Length of Wire (m)	Current in Loop (A)	Current in Solenoid (A)	Mass of String $(\times 10^{-5}\ \text{kg})$	Force $(\times 10^{-4}\ \text{N})$	Magnetic Induction $(\times 10^{-2}\ \text{N/A}\bullet\text{m})$
1	0.025	1.0	1.1	1.2		
2	0.025	1.0	1.9	2.3		
3	0.025	1.0	2.9	3.5		
4	0.025	1.0	4.0	4.7		
5	0.025	1.0	4.9	5.8		

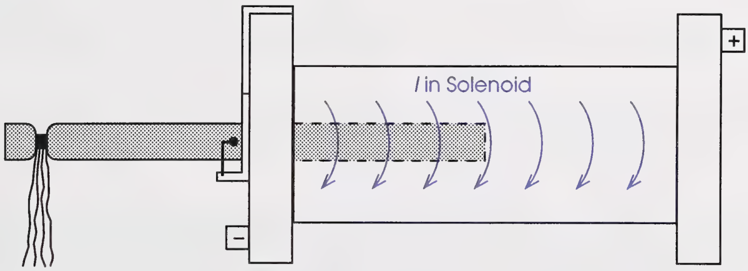
End of Part B

Analysis

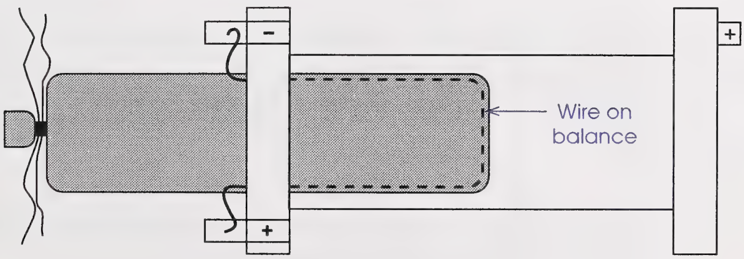
5. Calculate the force of gravity on the string for each trial. Show your calculations in your notebook. Record the forces on the data chart.

   - Before you calculate the magnetic field strength for the last column of the data chart, consider the current balance apparatus once more.

Side view



Top view showing the loop inside the solenoid



6. a. Copy the previous two diagrams into your notebook. Be careful to leave enough space to record your answers. Complete both diagrams by sketching the magnetic field that is created by the conventional current in the solenoid.

   b. Add an arrow and label to both diagrams to show the direction of conventional current flow within the loop of the current balance.

   c. Add arrows and labels to both diagrams to show the magnetic force that acts on the end of the loop and the gravitational force that acts on the pieces of string.

Check your answers by turning to the Appendix, Section 2: Activity 2.

The magnitude of the magnetic force acting on a current-carrying wire is directly proportional to the length of the wire (ℓ), the magnetic field strength $(B_\perp)$, and the current passing through the wire as long as all are perpendicular to each other. The equation for magnetic force is $F_m = I\ell B_\perp$.

7. Write an equation for the magnitudes of the two forces which are equal when the current balance is balanced.

8. Manipulate the equation for magnetic force to solve for $B_\perp$. Perform a unit analysis for the quantities within the equation to determine the units for $B_\perp$.

magnetic induction – the strength of a magnetic field

9. Use the manipulated equation to calculate the **magnetic induction** $(B_\perp)$ for each trial. Record these values in the data chart.

Check your answers by turning to the Appendix, Section 2: Activity 2.

10. Using the standard graph paper with 1-cm squares, plot a graph with current on the *x*-axis and magnetic induction on the *y*-axis. Be sure to leave ten squares for the horizontal axis and twelve squares for the vertical axis.

Conclusions

11. What does the graph indicate about the relationship between the magnetic induction and the current through the solenoid?

12. Imagine that the experiment was modified so that the current through the solenoid was kept constant. In this case, how could the loop be made to balance as more string was added on to the end outside the solenoid?

13. When the current balance is balanced, what can be said about the forces involved?

Check your answers by turning to the Appendix, Section 2: Activity 2.

You now have a detailed example of how a magnetic field can exert a force on a current-carrying wire. In the next activity you will extend this concept to a single charge moving into a magnetic field.

Activity 3: Applying the Magnetic Force

Consider this summary of a typical day for some people:

- 6:30 a.m. The clock radio plays your favourite radio station to help you wake up.
- 8:00 a.m. You jump into a vehicle and go to school or work.
- 4:45 p.m. You return home and do some vacuuming and help make supper.
- 10:00 p.m. You decide to watch TV as you unwind and get ready for bed.

What do all these events have in common? They all involve magnetic fields and the magnetic force. It's hard to think of how you could actually go through a day and **not** encounter applications of the magnetic force!

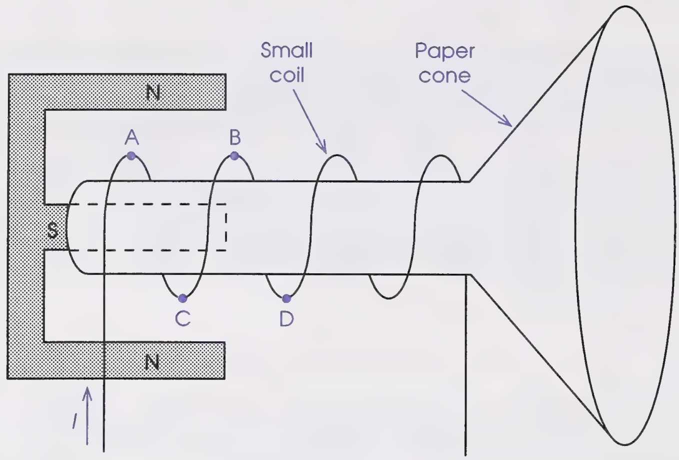
In this activity you will have an opportunity to explore many of these applications by referring to your textbook. Don't forget that the textbook uses only conventional current and that some of the names for the hand rules are slightly different.

Loudspeakers

All radios or stereos have a loudspeaker that is vibrating back and forth to set up sound waves in the air. The motion of the speaker cone is a consequence of the magnetic force. To find out how this operates, read the first paragraph on page 505 of your textbook. Pay close attention to Figure 24-22.

MERRILL
P•H•Y•S•I•C•S
PRINCIPLES AND PROBLEMS

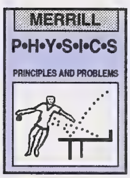
1. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram in your notebook by drawing the magnetic field lines set up by the permanent magnets and by labelling the direction of the conventional current through the coil at points A, B, C, and D.



2. Refer to the diagram in your notebook. Note that the coil is attached to the paper cone. Will the paper cone be forced in (towards the permanent magnets) or out (away from the permanent magnets)? Support your answer with a hand rule.

3. Refer to your answers for questions 1 and 2. Explain what would happen if the current ran through the small coil in the opposite direction.

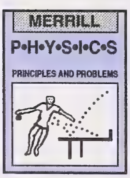
4. If the current in the coil changed directions a total of fifty times per second, would the sound from the speaker be a high-pitched tone or a low-pitched tone?



5. Do Problem 16 on page 512 of your textbook.

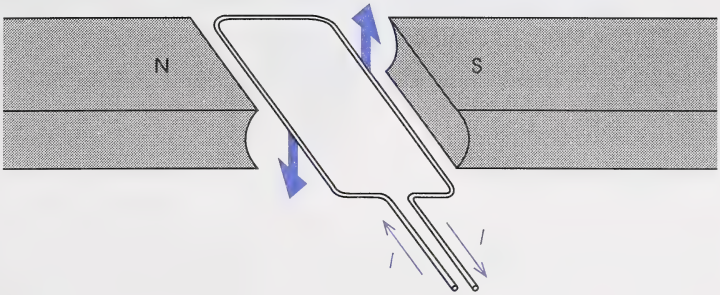
Check your answers by turning to the Appendix, Section 2: Activity 3.

Galvanometers



A galvanometer is a device that is used to measure very small electric currents. The operation of this device is due to the force experienced by a current-carrying wire in a magnetic field. Read the first two paragraphs of "Galvanometers," page 505 to the top of page 506 in the textbook.

6. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram in your notebook by sketching a hand to illustrate why the left side of the loop would be forced down and why the right side of the loop would be forced up.



7. Any current will produce the twisting effect shown in Figure 24-23 on page 505 of your textbook. Why doesn't the needle deflect to the extreme end of the scale, no matter what size of current is used?

Check your answers by turning to the Appendix, Section 2: Activity 3.

Ammeters

Galvanometers can be modified to measure larger amounts of current, in which case they are called ammeters. Carefully read the first paragraph on page 506 of your textbook, taking special note of Figure 24-24.

8. Why is it important for the shunt resistor to have a lower resistance than the small coil of wire in the galvanometer if the galvanometer is to be made into an ammeter?

9. Do Problem 19 on page 512 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Voltmeters

A galvanometer can also be modified to create a voltmeter. Read the second paragraph on page 506 of your textbook to discover how this is done.

10. Do Applying Concepts question 10 on page 511 of your textbook.

11. Do Problem 18 on page 512 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Electric Motors

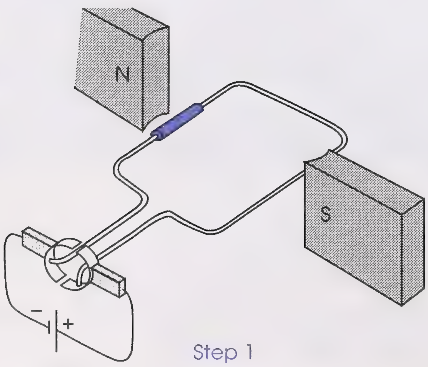
Think about the summary of a typical day that was given at the start of this activity. Electric forces would come into play to start the car's engine, operate the car's windshield wipers, and turn the fan in the vacuum cleaner. All of these are examples of electric motors in action, and all operate using the principles that you've been studying in this section.

Before you turn to the textbook, you should return to the program called *The Motor Principle* from the video series called *Electromagnetism*. Although you've already watched this ten-minute program, the last few minutes have a valuable computer animation sequence which shows how an electric motor works. You should watch this sequence again and look for similarities and differences between the operation of the electric motor and the galvanometer that you just studied.

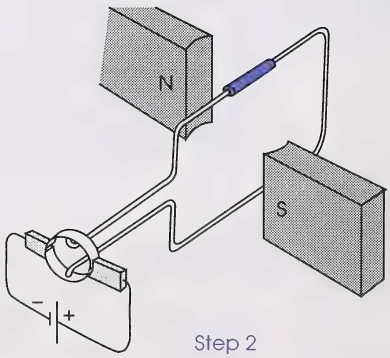
12. How is the design of an electric motor similar to that of a galvanometer?

13. One essential design difference is the presence of the **split-ring commutator** and the **brushes** in an electric motor. What function do these parts serve in the electric motor?

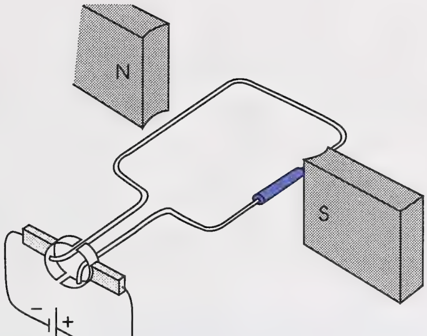
14. The following diagrams show steps in the operation of a simplified electric motor. Note that one part of the rotating loop has been made thicker and is coloured so that you can identify it.



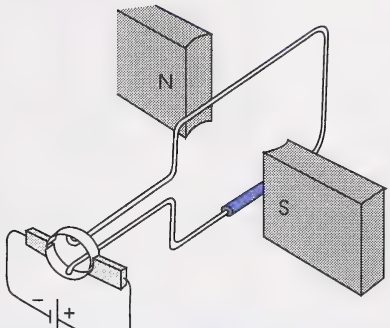
Step 1



Step 2



Step 3



Step 4

a. Describe the direction of the magnetic force on the thicker part of the loop in each step. Refer to a hand rule to support each answer.

b. Explain how your answers to question 14. a. relate to the motion of the loop.

Check your answers by turning to the Appendix, Section 2: Activity 3.

The textbook used almost the identical diagram as the videocassette did to describe the motion of electric motors. The only difference is that the videocassette describes events exclusively in terms of electron flow, and therefore refers to the left-hand rule for force. The textbook, on the other hand, describes the steps in terms of conventional current, and therefore uses the right-hand rule for force. However, since both sources are consistent in their explanations, the end description of the motor is correct in both cases.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

Read the last three paragraphs on page 506 of your textbook. Carefully examine Figure 24-25 as you read.

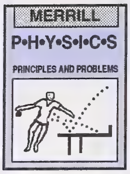
15. What is an armature?

16. How can the speed of a motor be increased?

Check your answers by turning to the Appendix, Section 2: Activity 3.

Television Picture Tube

This activity began with a summary of a typical day that ends with watching television before going to bed. Did you know that the picture on the screen is produced by an electron beam that is deflected by magnetic fields?



To find out more, read the first four paragraphs of "The Force on a Single Charged Particle," page 508 of your textbook. Pay particular attention to the derivation of the equation $F = Bqv$. You will be expected to use the version of the equation that is given in the Physics 30 data sheets, $F_m = qvB_\perp$.

17. Derive the equation $F_m = qvB_\perp$ from the equation $F_m = I\ell B_\perp$. Use a flow chart to communicate your answer. Show all steps and explanations for substitutions.

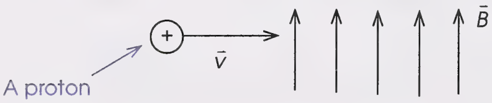
18. The textbook tries to explain that the direction of the force exerted by a magnetic field on an electron will be opposite to the direction given by the third right-hand rule.

    a. Why is the direction of the force opposite for electrons?

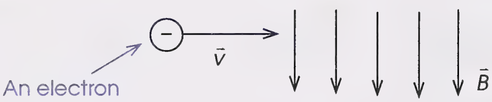
    b. How should you handle this situation?

19. Determine the direction of the magnetic force the instant the particle enters the magnetic field in each of the following diagrams. Explain your answers.

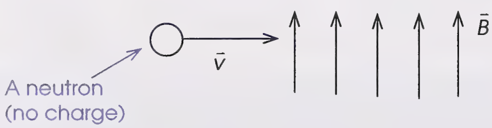
    a.



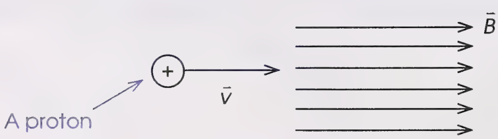
    b.



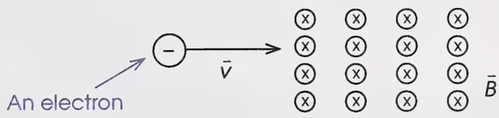
    c.



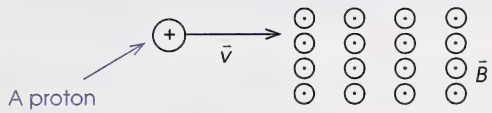
    d.



e.



f.



Check your answers by turning to the Appendix, Section 2: Activity 3.

You can see from the answers to the previous questions that the left-hand and right-hand rules for force apply as well to the case of individual particles as they did to the case of current-carrying conductors. The main thing to remember is to be consistent. Use your left hand for negative charges and electron flow and your right hand for positive charges and conventional current.

This can be summarized in the vector form of the equation.

Magnitude of the magnetic field (The perpendicular symbol reminds you that $\bar{v}$, $\bar{B}$, $\bar{F}_m$ are all perpendicular.)

The magnetic force acting on the particle → $\bar{F}_m = qvB_\perp$, with direction given by the hand rule for force

Speed of the particle

Magnitude of the charge

The sign of the charge determines which hand to use: positive – right hand, negative – left hand.

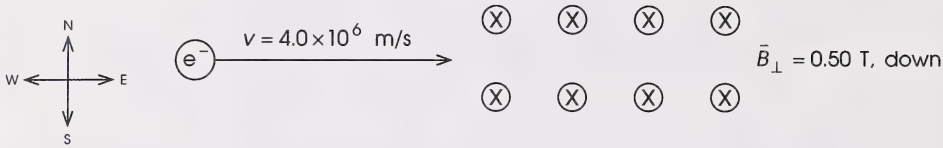
PHYSICS PRINCIPLES AND PROBLEMS

The Example Problem on page 508 of your textbook shows how the units work for a straightforward calculation. You should use the version of the equation presented in the Physics 30 data sheets.

20. Solve Practice Problem 13 on page 508 of your textbook. Be sure to use $F_m = qvB_\perp$ as you do the calculation.

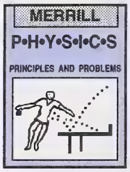
Now consider a three-dimensional diagram with the quantities from the previous question to determine the direction of the force on the electron.

21. Copy the following diagram into your notebook.



a. Apply the appropriate hand rule to determine the direction of the magnetic force exerted on the electron moving into *B*.

b. Combine your answer from question 21. a. with your answer to question 20 to state the magnitude and direction of the force.



22. Refer to Practice Problem 14 on page 509 of your textbook. Consider the direction of the particles to be straight up and the direction of the magnetic field to be from west to east. Use the data supplied in the Practice Problem to answer these questions.

a. Create a labelled diagram to help determine the direction of the force.

b. Calculate the magnitude of the force.

c. Combine your answers to questions 22. a. and b. to state the magnitude and direction of the force.

23. Refer to Practice Problem 15 on page 509 of your textbook. Consider the direction of the particles to be from east to west and the direction of the magnetic field to be from south to north. Use the data supplied in the Practice Problem to answer these questions.

a. Create a labelled diagram to help determine the direction of the force.

b. Calculate the magnitude of the force.

c. Combine your answers from questions 23. a. and b. to state the magnitude and direction of the force.

24. Refer to Practice Problem 16 on page 509 of your textbook. Consider the direction of the particles to be from north to south and the direction of the magnetic field to be vertically up. Use the data supplied in the Practice Problem to answer these questions.

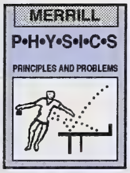
a. Create a labelled diagram to help determine the direction of the force.

b. Calculate the magnitude of the force.

c. Combine your answers from question 24. a. and b. to state the magnitude and direction of the force.

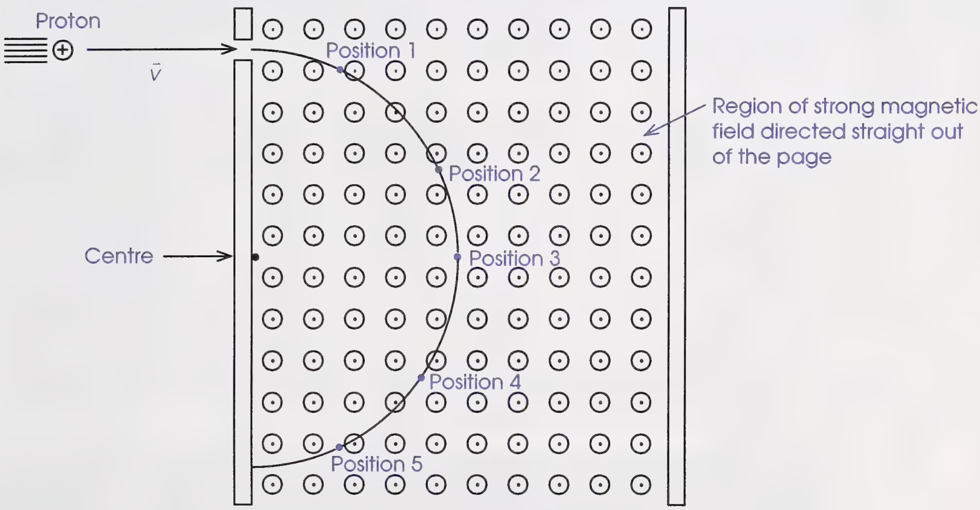
Check your answers by turning to the Appendix, Section 2: Activity 3.

Aurora Borealis (Northern Lights)



This is one of the most interesting applications of charged particles moving through magnetic fields. Read pages 490, 491, and the first and second paragraphs on page 508 of your textbook to discover how the northern lights relate to what you have learned in this section.

25. Copy the following diagram into your notebook. Note that you do not need to draw all the magnetic field vectors (⊙). Be careful to leave enough space to record your answers. Complete the diagram in your notebook by drawing vectors to represent the instantaneous velocity and the magnetic force at positions 1 through 5.



26. Refer to the definition of centripetal force and the diagram in the previous question to explain how F_m can be a centripetal force in this situation.

27. How would the diagram in question 25 change if it was an electron that entered this same strong magnetic field? Include a quick sketch with your answer.

28. When a charged particle travels at right angles to a uniform magnetic field, the radius of the path is given by the following equation.

$$\boxed{r = \frac{mv}{qB_{\perp}}}$$

Mass of particle

Speed of particle

Magnitude of the magnetic field (Note that the magnetic field is perpendicular to both $\vec{v}$ and $\vec{F}_m$.)

Radius of path

Magnitude of the charge on the particle

Derive this equation by starting with basic principles of circular motion. Use a flow chart to communicate your answer.

29. Solve Problems 24. b. and 25 on page 513 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

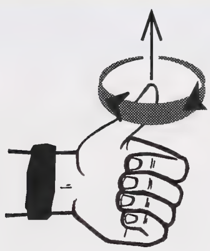
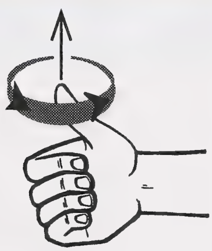
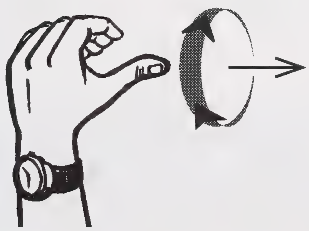
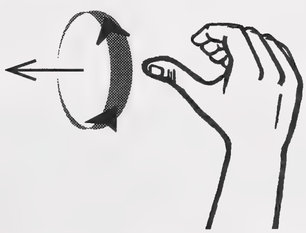
Extra Help

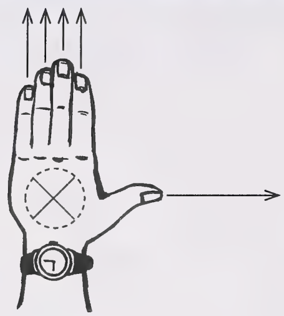
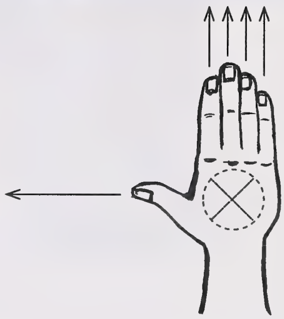
1. In this section you developed two new equations to describe the magnetic force. The following charts will allow you to summarize the key features of each equation. Copy the headings into your notebook. Be careful to leave enough space under each heading to record your answers.

Summarizing $F_m = I\ell B_{\perp}$			
Variable	Symbol	Unit	How is this variable considered in the hand rule?
Force			
Current			
Length			
Magnetic Field			

Summarizing $F_m = qvB_{\perp}$			
Variable	**Symbol**	**Unit**	**How is this variable considered in the hand rule?**
Force			
Charge			
Speed			
Magnetic Field			

2. This module has introduced you to three different hand rules. Since each one has a left- and right-hand version, there are six possibilities in total. Copy the following diagrams into your notebook. Note that you may decide only to draw the vectors if sketching the hands is too difficult. Be careful to leave enough space to record your answers. Complete the diagrams in your notebook by labelling each of the vectors indicated.

Rule	**Left-Hand Version**	**Right-Hand Version**
Rule for Conductors		
Rule for Coils		

Rule	Left-Hand Version	Right-Hand Version
Rule for Force		

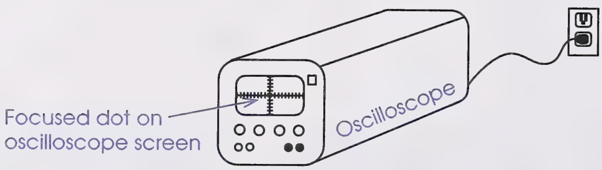
Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

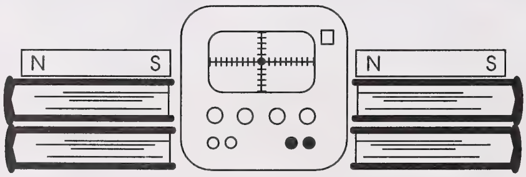
Do **one** of the following activities.

1. Observing Charged Particles in a Magnetic Field

   For this activity you will need an oscilloscope and two bar magnets. Adjust the oscilloscope so that the electron beam forms a focused dot in the centre of the screen, as shown in the following diagram.



   Turn off the oscilloscope and place the bar magnets along the centre horizontal grid line, as shown in the following diagram.

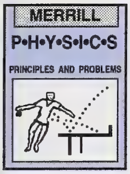


a. Make a prediction about the direction in which the electron beam will be deflected when the oscilloscope is turned back on.

b. Turn on the oscilloscope and verify your prediction. Did it work as you expected?

c. Try moving the bar magnets into a variety of different positions. In each case, predict what will happen to the electron beam and then turn on the oscilloscope to verify your prediction.

2. Magnetic Levitation Trains



Skim through pages 2 through 9 in your textbook to gather background information about superconductors and then read Physics and Technology on page 509.

a. The superconducting magnets that were initially used in the Japanese system required liquid helium. Identify two disadvantages of using liquid helium.

b. Explain how discoveries made in the late 1980s will allow the Japanese to make their system less expensive to operate.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

You should now have a clear sense of how magnetic phenomena play a crucial role in many of the technological devices that you use in your life. The left-hand and right-hand rules for force apply whether the magnetic force is acting on a current-carrying conductor, as in an electric motor, or on individual charged particles, as in a television.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

MODULE SUMMARY

In this module you have learned how magnetic fields can be created by permanent magnets, by straight current-carrying wires, and by solenoids. You have also seen that magnetic fields can exert forces on magnets and on charged particles. In the next module you will continue to develop and apply these concepts as you study electromagnetism.

Appendix

Glossary

Suggested Answers

Glossary

conventional current: the imaginary flow of positive charges through a conductor from positive to negative

domains: groups of neighbouring atoms that produce magnetic fields that align in the same direction

electromagnet: a series of current-carrying coils that produces a magnetic field similar to a bar magnet

left-hand rule for coils: a rule that shows the direction of the magnetic field inside a coil that is passing a flow of electrons

left-hand rule for conductors: a rule that shows the direction of the magnetic field around a conductor using electron flow

left-hand rule for force: a rule that shows the direction of the magnetic force acting on negative charges moving perpendicularly through a magnetic field

magnetic field: the region surrounding a bar magnet in which a magnetic force exists

magnetic field lines: lines along which a magnetic force exists within a magnetic field

magnetic flux: density of magnetic field lines in a given space or area

magnetic force: a force that exists within a magnetic field

magnetic induction: the strength of a magnetic field

motor principle: A magnetic force is exerted on a current-carrying wire that is placed at right angles to a magnetic field.

right-hand rule for coils: a rule that shows the direction of the magnetic field inside a coil that is passing a conventional current

right-hand rule for conductors: a rule that shows the direction of the magnetic field around a conductor using conventional current flow

right-hand rule for force: a rule that shows the direction of the magnetic force acting on positive charges moving perpendicularly through a magnetic field

solenoid: a coil of wire that is used to generate or detect strong magnetic fields

tesla: the unit for measuring magnetic field strength; 1 N/A•m

Suggested Answers

Section 1: Activity 1

1. Lodestone was used for navigation 2000 years ago.

2. a. You might have named substances such as iron, nickel, or cobalt.

   b. Answers may vary, but you may have predicted that magnetic properties are due to the structure of the atom, which in turn is a consequence of the behaviour of the electrons within the atom.

3. Electric energy is converted into mechanical energy.

4. Answers may vary. You may have listed any of these types of research or others.

   - examining the relationship between migrating birds and Earth's magnetic field
   - comparing the behaviours of organisms living near the north and south poles of Earth
   - testing the growth of unicellular plants and animals in strong magnetic fields

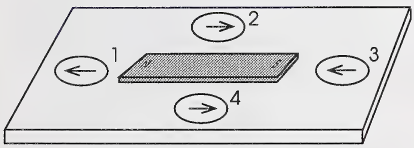
5. a. It is important to study and understand the concepts of magnetism because new applications may be found and applied in modern science.

   b. There are many correct answers to this question. You may have listed the following four uses or others:

   - electric devices
   - navigation
   - electromagnetic devices
   - new technology

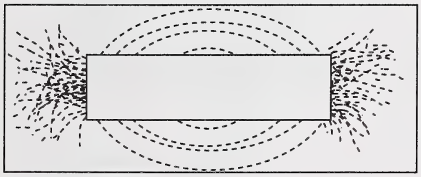
Section 1: Activity 2

1.



The north pole of the compass points away from the north pole, or towards the south pole, of the bar magnet.

2.



The iron filings are most concentrated at the two poles and form arcs between the poles.

3. The field lines do not overlap because the iron filings try to line up.

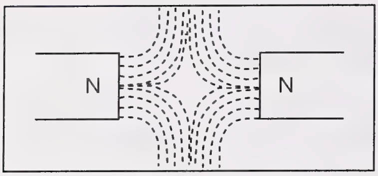
4. The magnetic flux is greatest at the poles because that is where the greatest concentration of magnetic field lines exists.

5. The iron filings stand up on the paper.

6. The magnetic field must be three-dimensional because the iron filings stand up and form a three-dimensional pattern.

7. When the two north poles are moved towards each other, the magnets push apart, or repel.

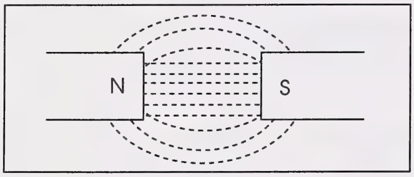
8. When the two south poles are moved towards each other, the magnets push apart, or repel.

9.


Your sketch should look like the one that is shown. The field lines of one north pole bend away from the field lines of the other. They repel each other.

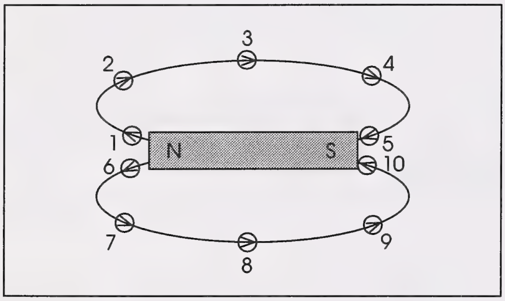
10. When the north and south poles of the magnets are moved towards each other, they are attracted to each other.

11. The two kinds of magnetic forces are attractive and repulsive.

12.


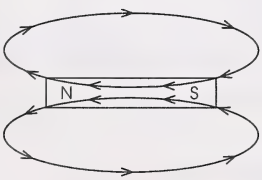
Your sketch should look like the one that is shown. The field lines run from the pole of one magnet to the opposite pole of the other magnet.

13. The north pole of the compass points away from the north pole of the bar magnet.

14.


The direction of the magnetic field outside the magnet is away from the north pole of a magnet and towards the south pole.

15. The north pole of the compass points towards the north pole of the bar magnet.

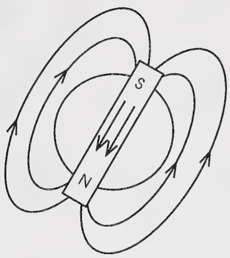
16.


The direction of the magnetic field lines outside a bar magnet is from north to south. Inside the bar magnet the magnetic field lines are from south to north.

17. The alignment of iron filings and the compass needle are the same, or parallel to each other.

18. There is no net force acting on the compass needle because it no longer deflects. There are lots of forces acting, magnetic and gravitational to mention two, but because the compass needle has no acceleration, the forces must balance. This is in accordance with Newton's second law, which says that when a net force acts on an object, the object will accelerate in the direction of the net force.

19.



20. The **magnetic south** pole of the imaginary magnet inside Earth lies under the **geographic north** pole of the planet. When people say that the extreme northern parts of Canada are close to the north pole, they are referring to the geographic north pole of Earth.

21.

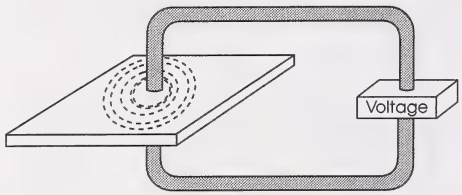
Characteristic of Field	Gravitational	Electric	Magnetic
What is the source or origin of this field?	a mass	a charge	a moving charge
What determines the direction of this field?	the direction of the gravitational force on a test mass	the direction of the electrostatic force on a positive test charge	the direction of magnetic force on the north end of a compass needle
Can this field exert both attractive and repulsive forces?	attractive only	attractive and repulsive	attractive and repulsive
How does the force exerted by the field change as the distance from the source increases?	decreases	decreases	decreases

Section 1: Activity 3

1. Both exert attractive forces over a distance.

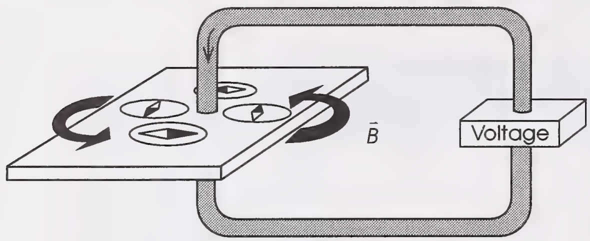
2. Hans Christian Oersted attempted to prove that electricity and magnetism were not related.

3. When Oersted placed the compass needle parallel to the conductor that was carrying electrons, the compass needle deflected. This observation suggested that electricity and magnetism are related.

4. 

The iron filings form concentric circles around the current-carrying wire.

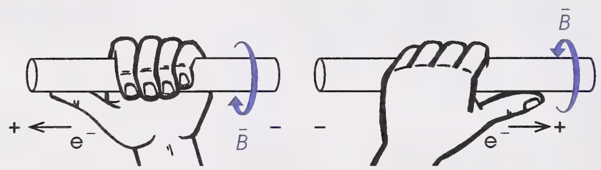
5. Electron flow is downwards.



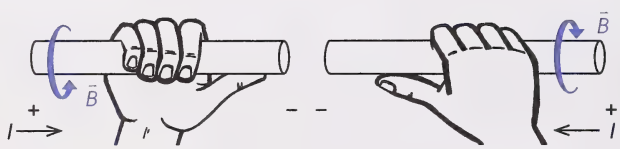
The magnetic field is counterclockwise.

6. The shape of the magnetic field remains the same when the direction of electron flow is reversed. Only the direction of the magnetic field changes.

7. Left-hand rule for electron flow:



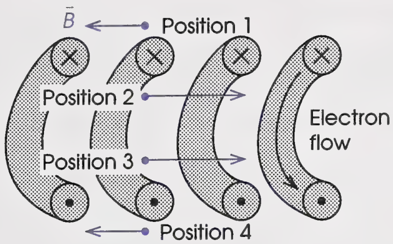
Right-hand rule for conventional current:



8. When a switch is opened in a circuit, the magnetic field collapses.

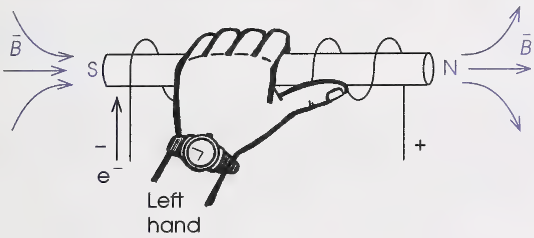
9. The symbol ⊙ is used to represent the direction straight out towards you and the symbol ⊗ is used to represent the direction away from you. This can be used to communicate the direction of conventional current or electron flow.

10.



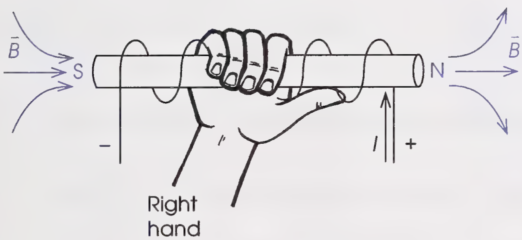
11. The magnetic field strength is stronger inside the coils because the magnetic field lines are more concentrated. This is so because the field lines from the top of the coil reinforce those at the bottom.

12.



The thumb points towards the north pole and shows the direction of $\vec{B}$ within the coil.

13.



The thumb points towards the north pole and shows the direction of $\vec{B}$ within the coil.

14. No, it does not matter whether you think in terms of electron flow or conventional current. The answers to the previous two questions indicate that the result is the same no matter which method is used. The important thing is to be consistent when using each rule. Use your left hand for electron flow and your right hand for conventional current.

15.

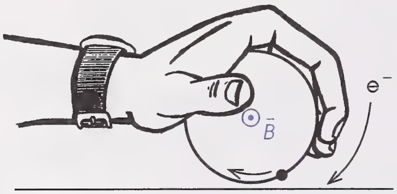
Comparing Permanent Bar Magnets to Electromagnets	
Two Similarities	**Two Differences**
Both objects have a north pole and a south pole.	The $\vec{B}$ for a bar magnet exists continually.
Both objects can attract things made of iron, cobalt, and nickel.	The $\vec{B}$ for an electromagnet exists only as long as there is charge flow through the coil.

16. The solutions to these problems can be found on page 683 of your textbook.

17. The solutions to these problems can be found on page 683 of your textbook.

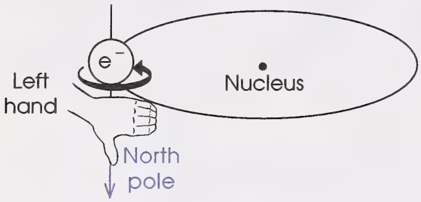
18. When an iron core is inserted into the coils of an electromagnet, the magnetic field strength is increased.

19.



Using the left-hand rule for coils, your fingers point in the direction of electron motion and your thumb points in the direction of the north pole, which is out of the plane of the page.

20.



Using the left-hand rule for coils, your fingers point in the direction of electron motion and your thumb points downwards along a line that is parallel to the plane of the page.

21. The random motion of electrons around the nucleus of an atom generates magnetic fields which cancel each other out.

22. Iron displays a net magnetic field because within its atomic structure four more electrons spin in one direction than in another direction.

23. The three ferromagnetic substances which display a net magnetic field are iron, nickel, and cobalt.

24. The magnetic dipoles are also thought of as tiny compass needles pointing north.

25. The term given to a cluster of dipoles which point in the same direction is a domain.

26. The magnetic field strength is increased when an iron bar is inserted into the coils of an electromagnet because the domains within the iron bar align in the same direction as the magnetic field of the electromagnet.

27. When current no longer flows through the electromagnet, the domains return to a random order.

28. The substance added to iron to prevent the domains from a random arrangement is carbon.

29. The poles on a broken permanent magnet would look like this.

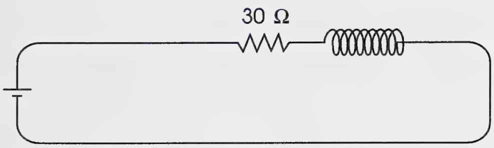
30. A permanent bar magnet can be destroyed by heating or by vibration. Both cause the domains to break free of their alignment.

31. Audiocassettes consist of a thin coating of bits of magnetic material attached to thin plastic. Computer floppy disks have a similar design. When a small area of this material passes by the recording head, which is basically an electromagnet, the domains in that small area are aligned according to the direction of the magnetic fields in the recording head. The whole audiocassette or disk then consists of a magnetic code that can store audio, video, or binary information.

32. Continents sit on huge plates that are moving very slowly. The plates that hold Africa and South America are drifting apart, creating a crack of volcanic activity that runs along the ocean floor. As the molten lava pours out, the domains in the liquid rock align with the magnetic field of the earth and then harden. This rock then becomes a permanent magnet and permanent record of the direction of the magnetic field of the earth when the rock solidified. By examining ancient rock formations that were poured out millions of years ago, and that have been pushed far from the crack, scientists have estimated that the magnetic field of the earth has alternated between north and south at least 171 times in the past 76 million years.

Section 1: Activity 4

1.



Your sketch should look like the one that is shown here.

2. The voltage reading across the solenoid should be between 0.80 V and 0.90 V.

3. The current in the circuit should be between 0.09 A and 0.12 A.

4. A sample calculation of the resistance for the 400-turn solenoid follows.

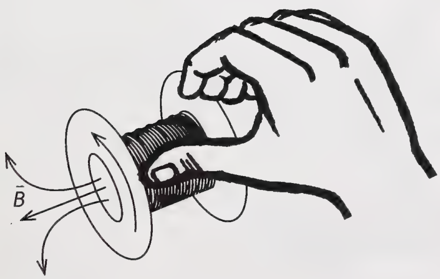
$V = 0.86\ \text{V}$

$I = 0.107\ \text{A}$

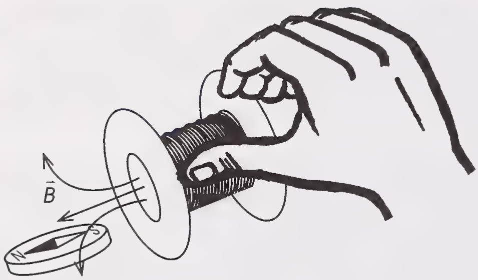
$R = ?$

$$
\begin{aligned}
V &= IR \\
R &= \frac{V}{I} \\
&= \frac{0.86\ \text{V}}{0.107\ \text{A}} \\
&= 8.04\ \Omega \\
&= 8.0\ \Omega
\end{aligned}
$$

5.



When the solenoid is positioned as illustrated, the north pole would be directed towards the left.

6. 

When a compass is placed at the end towards which your thumb points, the north pole of the compass points in the same direction as your thumb.

If your answers to the previous two questions are not consistent with each other, you need to start at the power supply and retrace the direction of charge flow through the solenoid.

7. The shape of the magnetic field surrounding the solenoid is similar to that of a bar magnet.

8. When the bolt is inserted into the centre of the solenoid, the magnetic field strength is stronger. This is consistent with the fact that the compass is deflected more.

9. The voltage across the 800-turn solenoid should be between 1.60 V and 1.70 V.

10. The current in the circuit should be between 0.080 A and 0.090 A.

11. A sample calculation of the resistance for the 800-turn solenoid follows.

$V = 1.65 \text{ V}$
$I = 0.086 \text{ A}$
$R = ?$

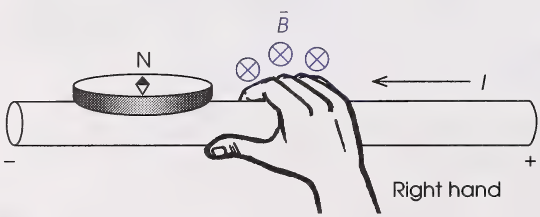
$$\begin{aligned} V &= IR \\ R &= \frac{V}{I} \\ &= \frac{1.65 \text{ V}}{0.086 \text{ A}} \\ &= 19.2 \ \Omega \\ &= 19 \ \Omega \end{aligned}$$

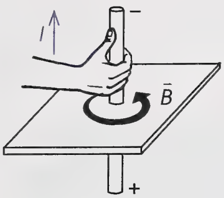
12. There is a greater resistance in the 800-turn solenoid because it has a greater length of wire, which results in a greater resistance.

13. The 800-turn solenoid has a greater magnetic field strength than the 400-turn solenoid. This is verified by the fact that the compass deflects a greater distance from the 800-turn solenoid.

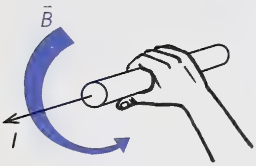
Section 1: Activity 5

1. Using the right-hand rule, where the thumb points in the direction of conventional current, the fingers of the right hand would point in the direction of the north pole of a compass, which would be into the plane of the page.



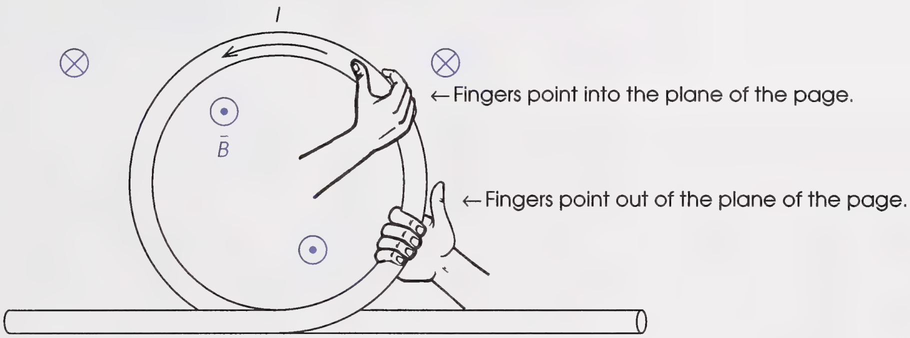
2. 

Using the right-hand rule, your fingers point in the direction of the magnetic field and your thumb points in the direction of conventional current flow, which is vertically upwards in the conductor.

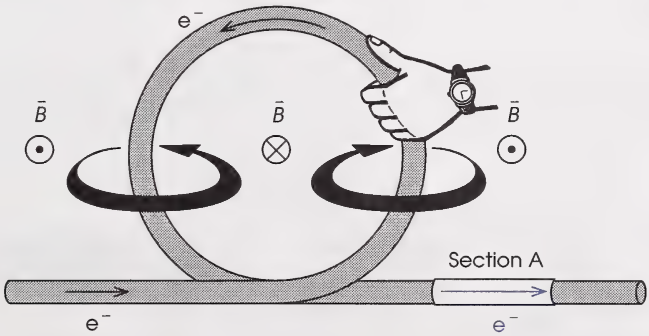
3. 

When a conductor is carrying current directly towards you, you can use the right-hand rule to determine that the direction of the magnetic field is counterclockwise.

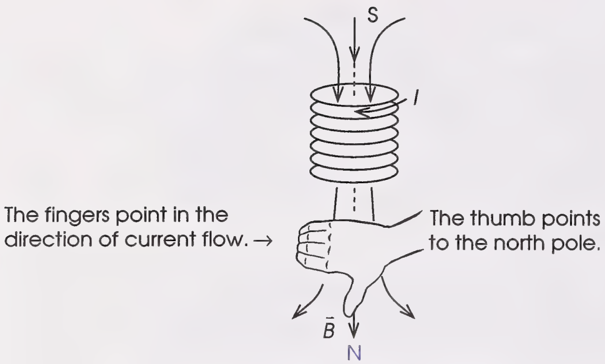
4. When you grasp the wire with your right hand so that your thumb points in the direction of conventional current flow (positive to negative), your fingers point in the direction of the magnetic field, or aligned with the north pole of the compass. At positions 1 and 4, the north pole of a compass would point into the plane of the page. At positions 2 and 3, the north pole would point out of the plane of the page.



5. In section A the electron flow would be directed to the right. This is determined using the left-hand rule for conductors.

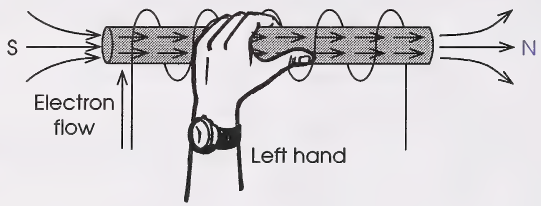


6.

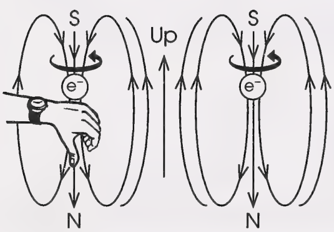


The north pole would be at the bottom of the coil.

7. When using the left-hand rule for coils, your fingers point in the direction of the electron flow through the coils and your thumb points towards the north pole. In this case the north pole would be on the right side. The domains would also align toward the right.



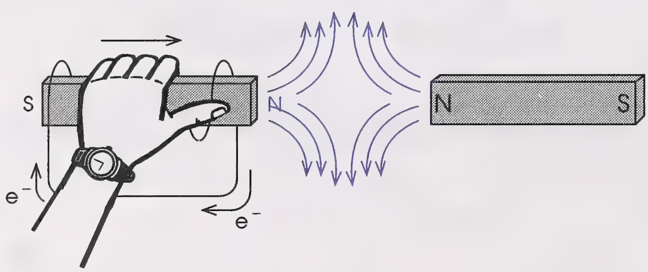
8.



The magnetic field between the electrons is in the same direction (up). Therefore, a net $\vec{B}$ would be present.

Note that the fingers of the left hand point in the direction of electron spin, while the thumb points towards the north pole.

9. Using the left-hand rule for coils to determine the direction of the north pole of the electromagnet verifies that the field lines would make the following pattern since the magnets repel each other. The right-hand rule for coils could also be used to give the same answer.



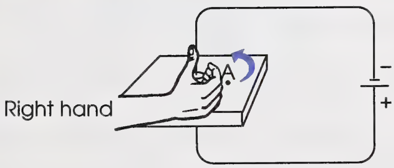
Section 1: Follow-up Activities

Extra Help

1.

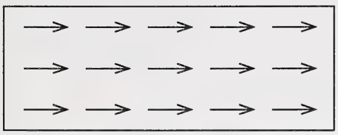
Summary Chart for Bar Magnets	
Direction of $\vec{B}$ Outside Bar Magnet	north to south
Direction of $\vec{B}$ Inside Bar Magnet	south to north
Region(s) Where $\vec{B}$ Is Most Concentrated	$\vec{B}$ is most concentrated at the north and south poles.
Kind of Force(s) Between Magnets	attractive and repulsive forces

2.

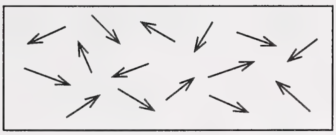


The right-hand rule for conventional current flow indicates that the magnetic field would be directed away from you, or into the plane of the page at point A. You would get the same answer if you correctly applied the left-hand rule for electron flow.

3.



Magnetized iron

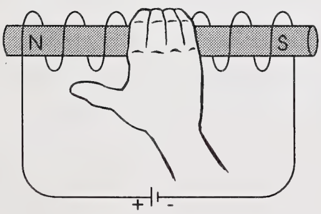


Unmagnetized iron

4. The magnetic field surrounding a solenoid could be increased the following ways:

- increasing the current through the coils
- increasing the number of turns of wire around the core
- inserting an iron core into the centre of the solenoid

5.



When using the right-hand rule for conventional current flow, your fingers point in the direction of current flow and your thumb points toward the north pole, which is on the left side of the electromagnet. You could get the same answer by applying the left-hand rule for electron flow.

Enrichment

1. a. When a piece of lodestone was suspended in the centre, it pointed in a north-south direction. Using lodestone as a simple compass led to an advancement in sea exploration.

   b. When iron filings were sprinkled around a lodestone sphere, they arranged themselves in lines that were concentrated at the poles.

   c. The arrangement of iron filings around a bar magnet on Earth has a two-dimensional pattern. In space the iron filings illustrate a three-dimensional pattern. Because there is no friction between the iron filings and paper in space, they are attracted towards the poles.

   d. Gilbert had concluded that the south magnetic pole is located in the northern hemisphere because the north pole of a compass is attracted to the opposite pole of Earth's magnetic field, or the south pole.

   e. When a bar magnet is heated, it loses its magnetic properties.

   f. Earth's magnetic field is believed to be the result of electrically charged iron rotating relative to Earth's mantle.

   g. The term *magnetic declination* is the angle between the geographic north pole and the magnetic north pole.

   h. The magnetic declination in Toronto is 9° W of N.

   i. The magnetic field line would be parallel to Earth's surface at the equator.

   j. The term given to the angle between Earth's surface and the field lines is called the angle of inclination.

   k. A dip needle is used to measure the angle of inclination at various positions above Earth's surface. When the dip needle is over the north magnetic pole, it would be perpendicular to Earth's surface.

   l. Compass navigation in the Arctic would not be very accurate because the compass would point downwards towards Earth's surface over the magnetic pole. More reliable means of navigation could include the global positioning systems (GPS). Such systems involve satellite communications which give latitude and longitude. During the day the sun could also be used for navigation.

2. The answers to this question will vary, depending on the resources that you chose. The following condensed sample contains many key points that will be common to all answers.

   Hans Christian Oersted was a Danish physicist who worked in his father's apothecary shop. He studied at the University of Copenhagen and obtained a PhD in physics. As well as pursuing his interests in physics, Oersted also developed an interest in chemistry which allowed him to isolate organic compounds. The greatest discovery of Oersted came in 1819 when he demonstrated that a compass placed near a current-carrying wire was deflected at right angles to the wire. Oersted had experimentally indicated that there was a definite connection between electricity and magnetism.

Section 2: Activity 1

1. Oersted discovered that a current-carrying wire generates a circular magnetic field that will deflect a compass.

2. a. This device is called a rail gun.

   b. The rails must each be carrying a flow of charge, but the charge must move in opposite directions within each rail.

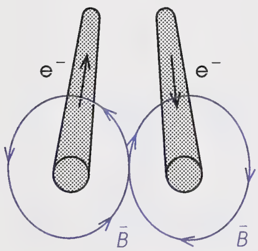
   c. The projectile is a conductor that is designed to allow the charge to pass from one rail to the other.

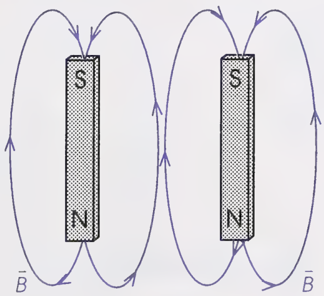
   d. The rails will strongly repel one another.

3. a. When the electrons flow in the same direction in both wires, the wires attract.

   b. When the electrons flow in opposite directions in the wires, the wires repel.

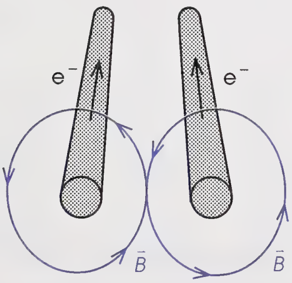
   c.

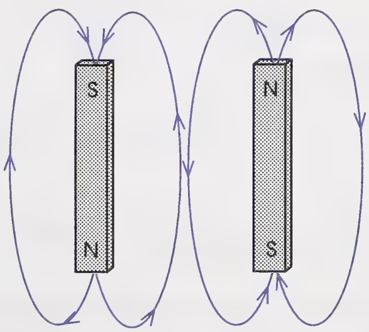




   d. In both cases the magnetic field lines flow in the same direction in the region between the objects. Since the magnets repel each other, this suggests that the wires should also repel.

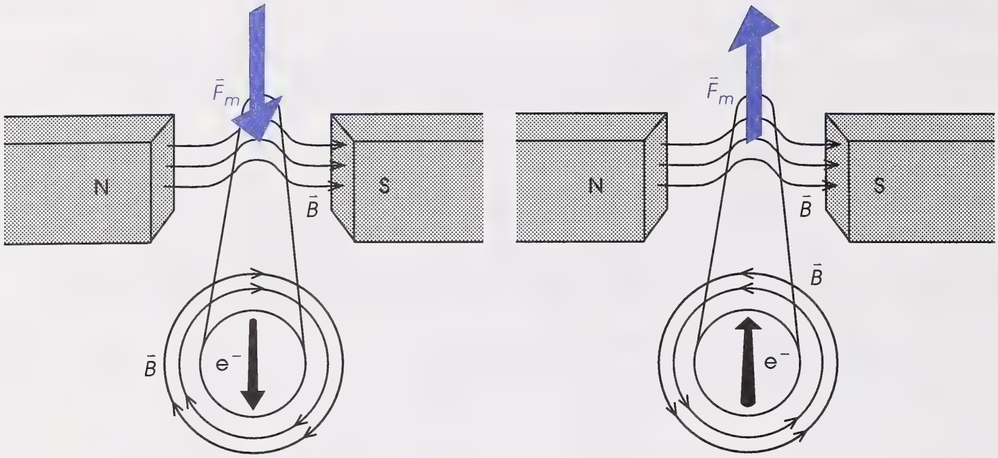
   e.



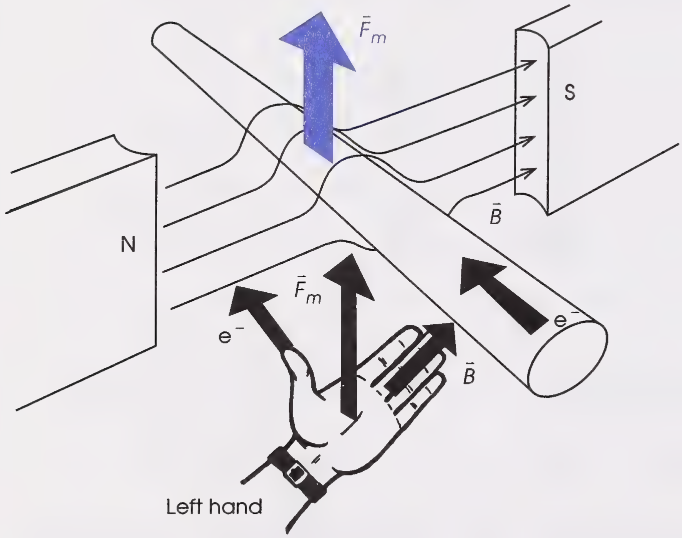


   f. In both cases the field lines run in opposite directions in the region between the objects. Since the magnets attract each other, this suggests that the wires should also attract.

4.



5.



6. The motor principle gets its name because the first application of this idea was in the design of electric motors.

7. a. No, the circuits are the same. The positive terminal of the voltage source is on the right and the negative terminal is on the left in both examples.

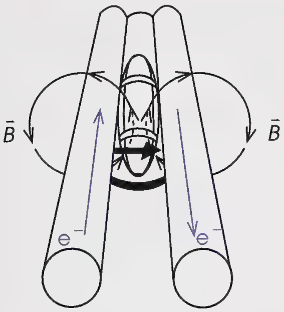
   b. No, there is no difference in the direction of the magnetic force. In both cases the magnetic force is directed upwards.

   c. No, it does not matter which system you use. The result of the force being directed upwards is the same.

   d. The important thing is to be consistent. When thinking about electron flow, use the left hand, and when thinking about conventional current, use the right hand.

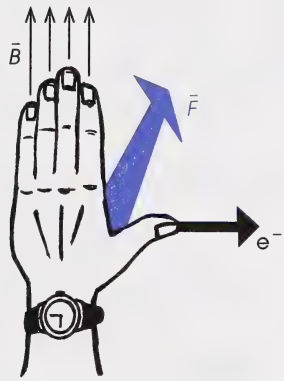
8. The circuits are the same, so the direction of the magnetic force is the same.

9.



10. This question is answered on the diagram for question 9.

11. As shown in the accompanying sketch, the correct application of the left-hand rule for forces predicts that the projectile should be forced away from you, down the rails.



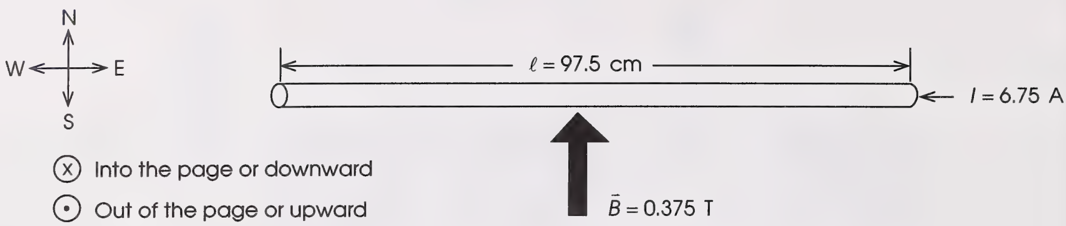
12. a. $1\ \text{T} = \dfrac{1\ \text{N}}{\text{A} \bullet \text{m}}$

b. $$\begin{aligned} 1\ \text{T} &= \frac{1\ \text{N}}{\text{A} \bullet \text{m}} \\ &= \frac{1\ \text{kg} \bullet \cancel{\text{m}}/\text{s}^{\cancel{2}}}{\text{C}/\cancel{\text{s}} \bullet \cancel{\text{m}}} \\ &= \frac{1\ \text{kg}/\text{s}}{\text{C}} \\ &= \frac{1\ \text{kg}}{\text{C} \bullet \text{s}} \end{aligned}$$

c. The average value for Earth's magnetic field strength is 5×10^{-5} T.

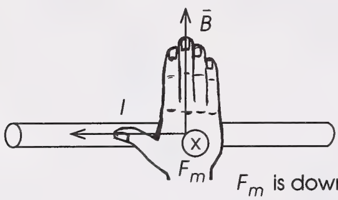
13. If an archer shot an arrow directly towards you, along your line of sight, all that you would see is the point directly in the centre of the arrowhead. This would look like this: ⊙. If you watched an arrow move directly away from you, along your line of sight, all that you would see would be the crossed feathers at the end of the arrow against the background of the arrowhead. This would look like this: ⊗.

14. a.



b. $$F_m = I\ell B_\perp$$
$$= (6.75\ \text{A})(0.975\ \text{m})(0.375\ \text{T})$$
$$= 2.47\ \text{N}$$

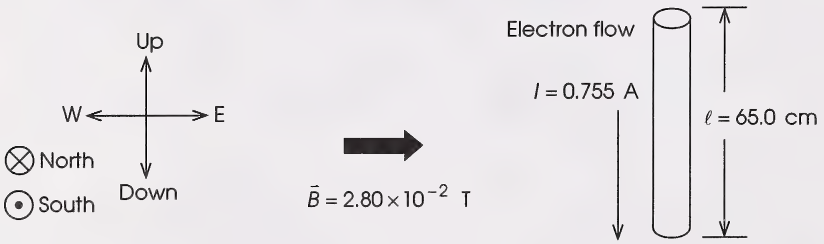
c. Use the right-hand rule for conventional current to determine the direction of the magnetic force acting on the wire.



F_m is downward, towards the surface of Earth.

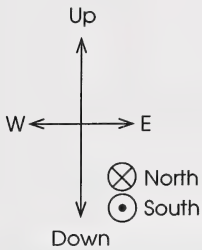
d. $\vec{F}_m = 2.47 \times 10^{-1}$ N, downwards (towards the surface of Earth)

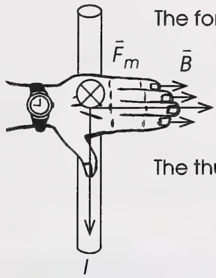
15. a.



b. $$F_m = I\ell B_\perp$$
$$= (0.755\ \text{A})(0.650\ \text{m})\left(2.80 \times 10^{-2}\ \text{T}\right)$$
$$= 1.37 \times 10^{-2}\ \text{N}$$

c. Use the left-hand rule for force to determine the direction of the magnetic force on the wire.

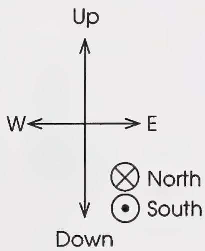


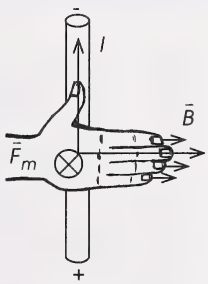


The force points north, or into the plane of the page.

The thumb points downwards in the direction of electron flow.

Note: If you use the right-hand rule for conventional current, the thumb would now point upwards along the wire, but the direction of the magnetic force is still north, or into the plane of the page.



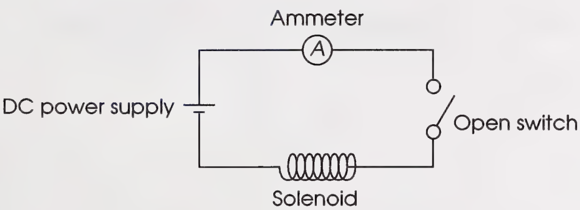


d. $\vec{F}_m = 1.37 \times 10^{-2}$ N, north, or into the plane of the page

16. Answers to these problems can be found on page 683 of your textbook.

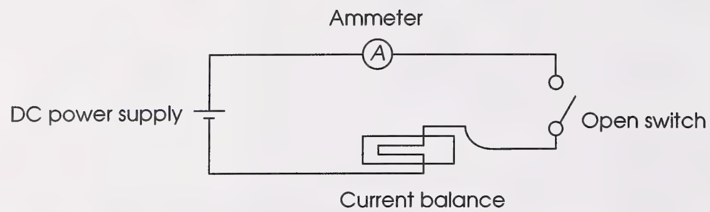
Section 2: Activity 2

1.



2. The length of the wire across the end of the current balance is typically about 2.5 cm. Your answers may vary depending on the equipment available to you.

3.



The following is a sample data chart like the one you should have copied in your notebook. The last two columns have been filled in with values from the calculations which follow.

Trial	Length of Wire (m)	Current in Loop (A)	Current in Solenoid (A)	Mass of String $(\times 10^{-5}\ \text{kg})$	Force $(\times 10^{-4}\ \text{N})$	Magnetic Induction $(\times 10^{-2}\ \text{N/A}\bullet\text{m})$
1	0.025	1.0	1.1	1.2	1.2	0.48
2	0.025	1.0	1.9	2.3	2.3	0.92
3	0.025	1.0	2.9	3.5	3.4	1.4
4	0.025	1.0	4.0	4.7	4.6	1.8
5	0.025	1.0	4.9	5.8	5.7	2.3

4. When the string is placed on the adjusting nut of the current balance, the end outside the solenoid dips downwards.

5. Sample calculation for the force of gravity of the string.

Trial 1: $m = 1.2 \times 10^{-5}$ kg

$g = 9.81\ \text{m/s}^2$

$W = F_g = ?$

$$\begin{aligned} F_g &= mg \\ &= \left(1.2 \times 10^{-5}\ \text{kg}\right)\left(9.81\ \text{m/s}^2\right) \\ &= 1.177 \times 10^{-4}\ \text{N} \\ &= 1.2 \times 10^{-4}\ \text{N} \end{aligned}$$

The other values follow.

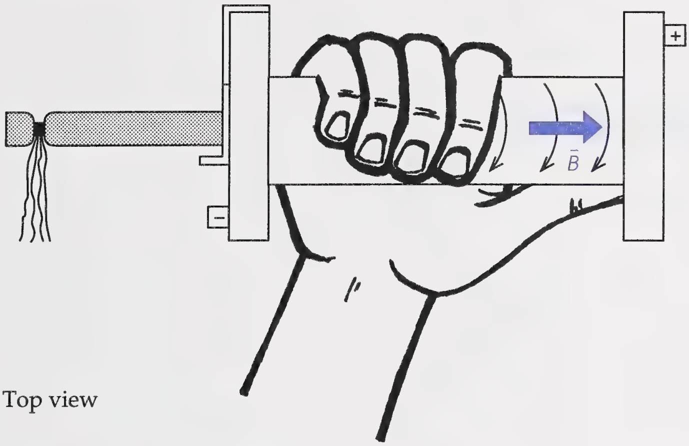
Trial 2: $F_g = 2.3 \times 10^{-4}$ N

Trial 3: $F_g = 3.4 \times 10^{-4}$ N

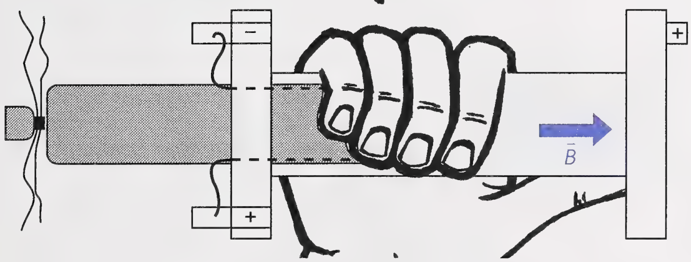
Trial 4: $F_g = 4.6 \times 10^{-4}$ N

Trial 5: $F_g = 5.7 \times 10^{-4}$ N

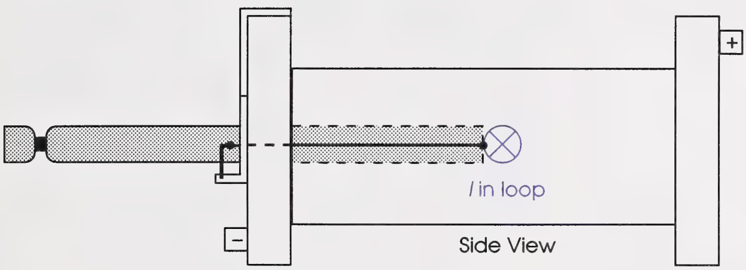
6. a. Side view



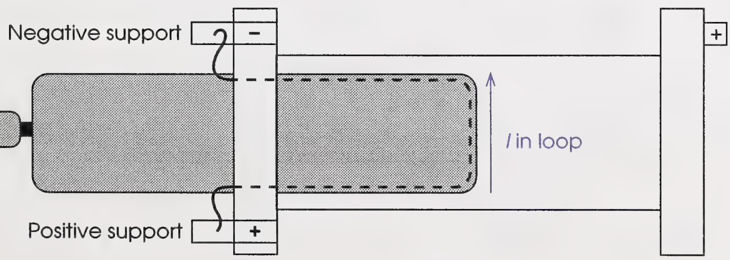
Top view



b. Side view

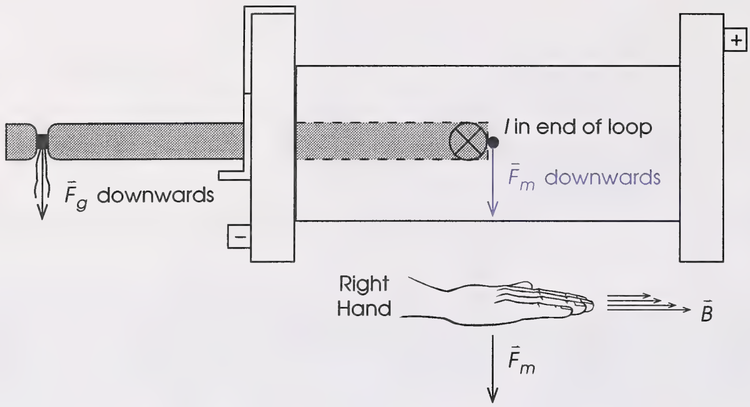


Top view

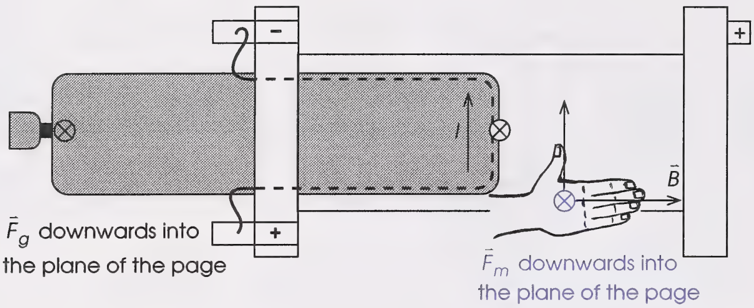


To determine the direction of current through the loop, trace the flow of conventional current from the positive support, through the loop, and back to the negative support.

c. Side view



Top view



7. The equation for the two balanced forces for the current balance is as follows:

$$F_g = F_m$$
$$mg = I\ell B_{\perp}$$

8. $F_g = F_m$

$$mg = I\ell B_{\perp}$$
$$B_{\perp} = \frac{mg}{I\ell}$$

Unit analysis for the units for B.

$$\boxed{B_{\perp} = \frac{F_m}{I\ell}}$$

Substitute units.

$$\boxed{\mathrm{T} = \frac{\mathrm{N}}{\mathrm{A} \bullet \mathrm{m}}}$$

Units for $B_{\perp} = \frac{\mathrm{N}}{\mathrm{A} \bullet \mathrm{m}}$

9. Trial 1:

$$F_g = 1.2 \times 10^{-4}\ \text{N}$$
$$I = 1.0\ \text{A}$$
$$\ell = 0.025\ \text{m}$$
$$B_\perp = ?$$

$$\begin{aligned} B_\perp &= \frac{mg}{I\ell} \\ &= \frac{\left(1.2 \times 10^{-4}\ \text{N}\right)}{(1.0\ \text{A})(0.025\ \text{m})} \\ &= 4.8 \times 10^{-3}\ \text{N/A} \bullet \text{m} \end{aligned}$$

Trial 2:

$$F_g = 2.3 \times 10^{-4}\ \text{N}$$
$$I = 1.0\ \text{A}$$
$$\ell = 0.025\ \text{m}$$
$$B_\perp = ?$$

$$\begin{aligned} B_\perp &= \frac{mg}{I\ell} \\ &= \frac{\left(2.3 \times 10^{-4}\ \text{N}\right)}{(1.0\ \text{A})(0.025\ \text{m})} \\ &= 9.2 \times 10^{-3}\ \text{N/A} \bullet \text{m} \end{aligned}$$

Trial 3:

$$F_g = 3.4 \times 10^{-4}\ \text{N}$$
$$I = 1.0\ \text{A}$$
$$\ell = 0.025\ \text{m}$$
$$B_\perp = ?$$

$$\begin{aligned} B_\perp &= \frac{mg}{I\ell} \\ &= \frac{\left(3.4 \times 10^{-4}\ \text{N}\right)}{(1.0\ \text{A})(0.025\ \text{m})} \\ &= 1.4 \times 10^{-2}\ \text{N/A} \bullet \text{m} \end{aligned}$$

Trial 4:

$$F_g = 4.6 \times 10^{-4}\ \text{N}$$
$$I = 1.0\ \text{A}$$
$$\ell = 0.025\ \text{m}$$
$$B_\perp = ?$$

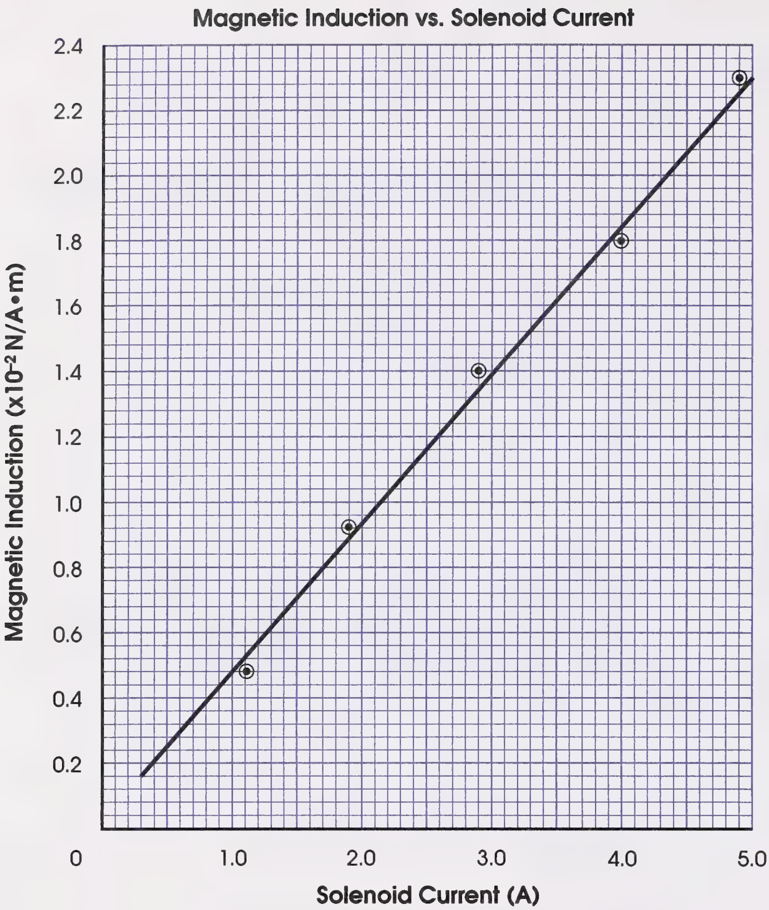
$$\begin{aligned} B_\perp &= \frac{mg}{I\ell} \\ &= \frac{\left(4.6 \times 10^{-4}\ \text{N}\right)}{(1.0\ \text{A})(0.025\ \text{m})} \\ &= 1.8 \times 10^{-2}\ \text{N/A} \bullet \text{m} \end{aligned}$$

Trial 5:

$$F_g = 5.7 \times 10^{-4}\ \text{N}$$
$$I = 1.0\ \text{A}$$
$$\ell = 0.025\ \text{m}$$
$$B_\perp = ?$$

$$\begin{aligned} B_\perp &= \frac{mg}{I\ell} \\ &= \frac{\left(5.7 \times 10^{-4}\ \text{N}\right)}{(1.0\ \text{A})(0.025\ \text{m})} \\ &= 2.3 \times 10^{-2}\ \text{N/A} \bullet \text{m} \end{aligned}$$

10.



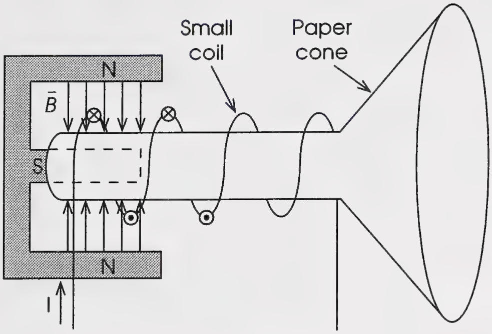
11. The magnetic induction versus solenoid current graph is a straight line which indicates that magnetic induction varies directly with the current passing through the solenoid. As solenoid current increases, magnetic induction increases.

12. If the current in the solenoid was kept constant, you would have to increase the current through the loop to balance the addition of more string.

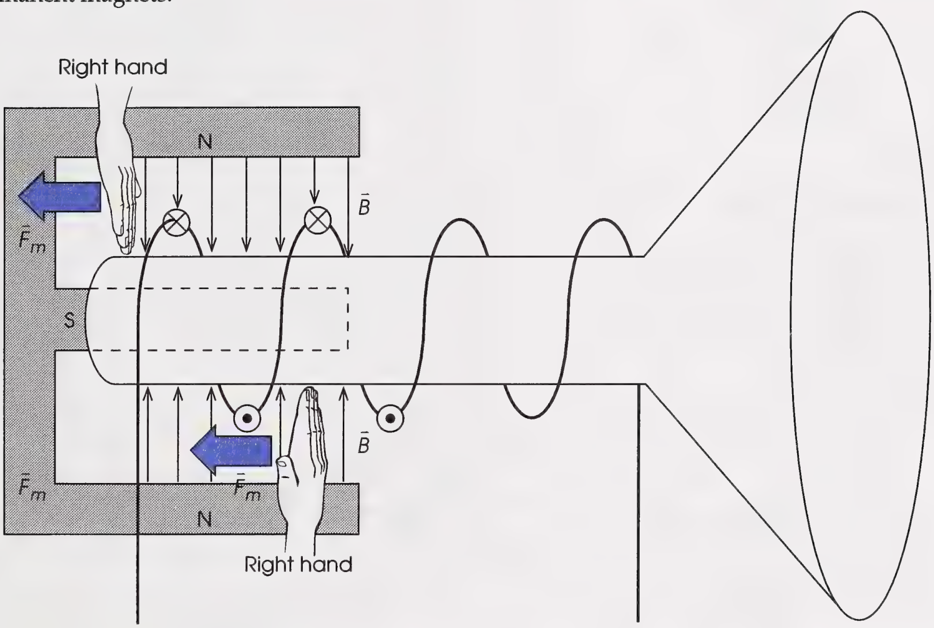
13. The magnetic force is in equilibrium with the gravitational force when the current balance is balanced.

Section 2: Activity 3

1.



2. As the following enlarged diagram indicates, the coils experience a force back towards the permanent magnets, as predicted by the right-hand rule for force. The coil and the paper cone are attracted in, towards the permanent magnets.



3. If the current ran through the coil in the opposite direction, the force would be in the opposite direction, forcing the paper cone and small coil away from the permanent magnets.

4. If the frequency of the changing current was 50 Hz, the frequency of the cone movement and the frequency of the sound produced would also be 50 Hz. This is a low-pitched tone.

5. Textbook question 16:

$B_\perp = 0.15\ \text{T}$

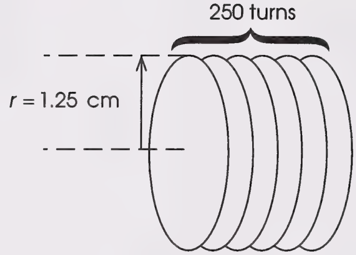
$n = 250\ \text{turns}$

$\text{diameter} = 2.5\ \text{cm}$

$R = 8.0\ \Omega$

$V = 15\ \text{V}$

$F = ?$



Step 1: Calculate the total length of the wire in the field.

$$\begin{aligned}\text{length} &= (\text{circumference})(\text{number of turns})\\ &= (2\pi r)(250)\\ &= 2\pi(1.25\ \text{cm})(250)\\ &= 1.96\times 10^3\ \text{cm}\\ &= 19.6\ \text{m}\end{aligned}$$

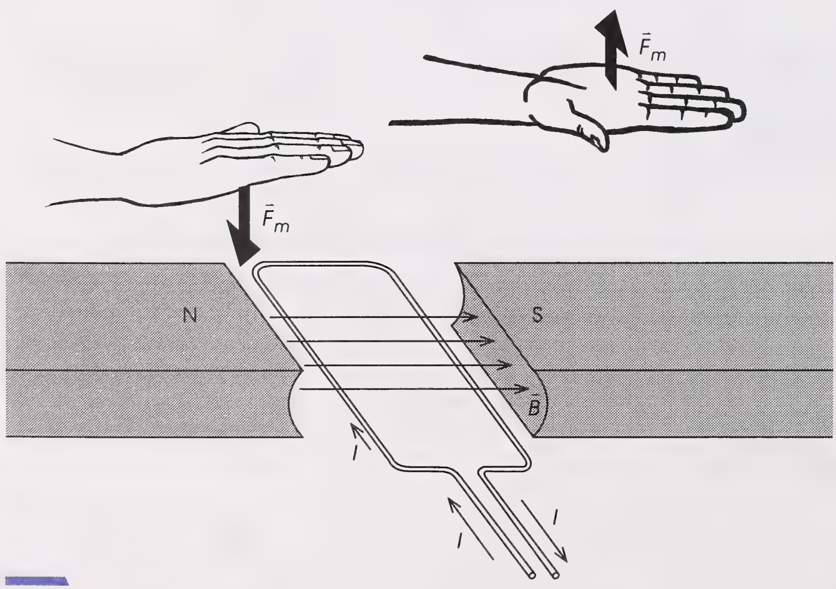
Step 2: Calculate the current flowing through the coil.

$$\begin{aligned}V &= IR\\ I &= \frac{V}{R}\\ &= \frac{15\ \text{V}}{8.0\ \Omega}\\ &= 1.875\ \text{A}\\ &= 1.9\ \text{A}\end{aligned}$$

Step 3: Calculate the force.

$$\begin{aligned}F_m &= I\ell B_\perp\\ &= (1.875\ \text{A})(19.6\ \text{m})(0.15\ \text{T})\\ &= 5.5\ \text{N}\end{aligned}$$

6.



7. The spring counteracts the twisting effect of the magnetic force so that the needle is held in equilibrium.

8. It is important for the shunt resistor to have a lower resistance so that most of the current will flow through it, leaving only a small portion of the original current to flow through the coil.

9. Textbook question 19. a.:

$$R = 1\ \text{k}\Omega = 1\times10^{3}\ \Omega$$
$$I = 50\ \mu\text{A} = 50\times10^{-6}\ \text{A}$$
$$V = ?$$

$$\begin{aligned} V &= IR \\ &= \left(50\times10^{-6}\ \text{A}\right)\left(1\times10^{3}\ \Omega\right) \\ &= 0.05\ \text{V} \end{aligned}$$

Textbook question 19. b.:

$$R_T = ?$$
$$V = 0.05\ \text{V}$$
$$I = 10\ \text{mA} = 10\times10^{-3}\ \text{A}$$

$$\begin{aligned} V &= IR_T \\ R_T &= \frac{V}{I} \\ &= \frac{(0.05\ \text{V})}{\left(10\times10^{-3}\ \text{A}\right)} \\ &= 5\ \Omega \end{aligned}$$

Textbook question 19. c.:

$$R_T = 5\ \Omega$$
$$R_{gal} = 1\ \text{k}\Omega$$
$$R_{shunt} = ?$$

$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}}$$ For resistors connected in parallel

$$\begin{aligned} \frac{1}{R_T} &= \frac{1}{R_{gal}} + \frac{1}{R_{shunt}} \\ \frac{1}{R_{shunt}} &= \frac{1}{R_T} - \frac{1}{R_{gal}} \\ &= \frac{1}{(5\ \Omega)} - \frac{1}{(1000\ \Omega)} \\ &= \left(0.200\ \Omega^{-1}\right) - \left(0.001\ \Omega^{-1}\right) \\ \frac{1}{R_{shunt}} &= 0.199\ \Omega^{-1} \\ R_{shunt} &= 5.025\ \Omega \\ &= 5\ \Omega \end{aligned}$$

10. Textbook question 10:

When the value of the resistor is increased in a voltmeter, the current that is allowed to pass to the coil is reduced. This enables the voltmeter to respond to a higher range of voltages.

11. Textbook question 18. a.:

$I = 50.0\ \mu\text{A} = 50.0 \times 10^{-6}\ \text{A}$

$V = 10.0\ \text{V}$

$R_T = ?$

$$\begin{aligned} V &= IR_T \\ R_T &= \frac{V}{I} \\ &= \frac{10.0\ \text{V}}{50.0 \times 10^{-6}\ \text{A}} \\ &= 2.00 \times 10^5\ \Omega \end{aligned}$$

Textbook question 18. b.:

$R_{multiplier} = ?$

$R_{gal} = 1.0\ \text{k}\Omega$

$R_T = 2.0 \times 10^5\ \Omega$

$$\boxed{R_T = R_1 + R_2}$$ For resistors in series

$$\begin{aligned} R_T &= R_{multiplier} + R_{gal} \\ R_{multiplier} &= R_T - R_{gal} \\ &= \left(2.00 \times 10^5\ \Omega\right) - (1\ \text{k}\Omega) \\ &= 1.99 \times 10^5\ \Omega \end{aligned}$$

12. Both the electric motor and the galvanometer are designed to produce a rotational effect on a current-carrying loop within a region of a strong magnetic field.

13. The split-ring commutator allows the direction of charge flow to reverse itself every half cycle. This allows the current-carrying loops to continue to spin. The brushes provide contact and a conducting path between the voltage supply and the split-ring commutator. Since the split-ring commutator is continually turning, the brushes must be designed to maintain contact on this moving curved surface.

14. a. This question can be answered using either the left or the right-hand rule for force. In step 1 the thicker part of the loop will experience on upward force, while in step 3 the thicker part of the loop experiences a downward force. The overall effect of these two forces is to cause the loop to rotate. At steps 2 and 4 the forces are still directed up and down, which does not add to the rotation.

    b. The forces on the loop in steps 2 and 4 do not add to the rotation, but the inertia of the loop causes it to move past these positions anyway. Once the loop has moved past the vertical position, the split-ring commutator reverses the direction of the current, which creates forces that cause the rotation to continue.

15. An armature is the name given to the moving part of an electric motor which consists of many loops spinning in a magnetic field.

16. The speed of a motor can be increased by increasing the force acting on the armature. This force is described by the equation $F_m = I\ell B_{\perp}$. It follows that the force can be increased by increasing the current through the loops of the armature, by increasing the number of loops (length of wire), or by increasing the strength of the magnetic field.

17.

$$F_m = I\ell B_{\perp} \qquad I = \frac{q}{t} \qquad v = \frac{d}{t}$$

Rearrange.

$$d = vt$$

$\ell = d$

$$\ell = vt$$

Substitute.

Substitute.

$$F_m = \left(\frac{q}{t}\right)(vt)B_{\perp}$$

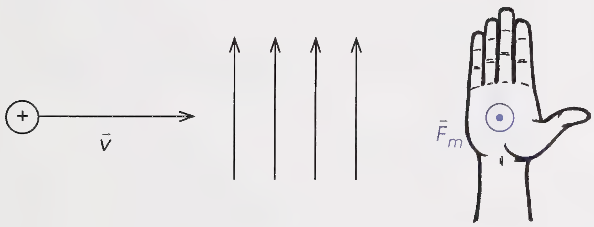
Cancel the time from the numerator and the denominator.

$$F_m = qvB_{\perp}$$

18. a. Electrons have a negative charge, which means that they will be forced in the opposite direction of positive charges. The third right-hand rule is the textbook's term for the right-hand rule for force.

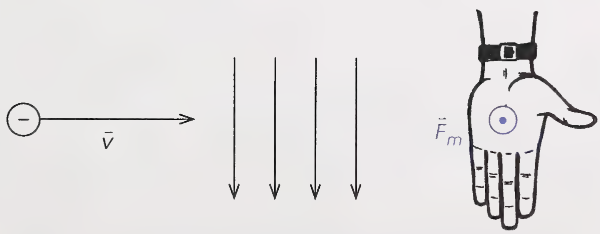
b. The easiest solution is simply to use the left-hand rule for force, which automatically gives the proper direction for electrons.

19. a.



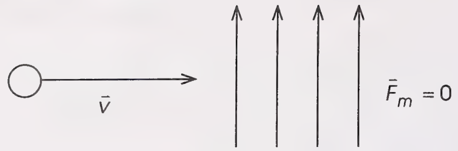
The right-hand rule for force predicts that the force will be directed straight up from the page.

b.



The left-hand rule for force predicts that the force will be directed straight up from the page.

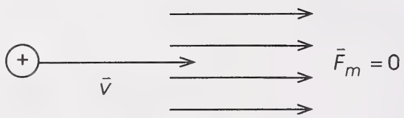
c.



Since the neutron has no charge, there will be no force exerted on it.

$$
\begin{aligned}
F_m &= qvB_\perp \\
&= (0)vB_\perp \\
&= 0
\end{aligned}
$$

d.



The equation has the perpendicular symbol on the magnetic field variable to remind you that it is only the part of $\vec{v}$ that is perpendicular to $\vec{B}$ that matters.

Since the vectors are parallel here, there is no perpendicular component.

e.

The left-hand rule for force indicates that the electrons will be forced towards the bottom of the page.

f.

The right-hand rule for force indicates that the protons will be forced towards the bottom of the page.

20. Textbook question 13:

$q = -1.60 \times 10^{-19}$ C

$v = 4.0 \times 10^{6}$ m/s

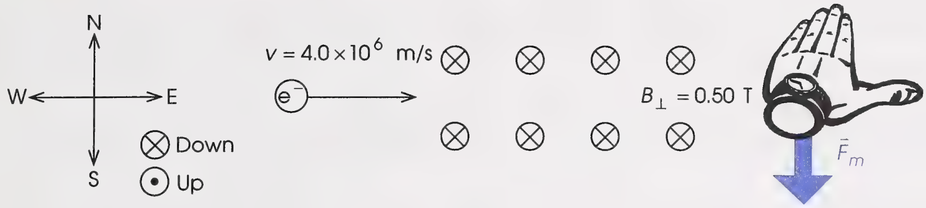
$B_\perp = 0.50$ T

$F_m = ?$

$$
\begin{aligned}
F_m &= qvB_\perp \\
&= \left(1.60 \times 10^{-19}\ \text{C}\right)\left(4.0 \times 10^{6}\ \text{m/s}\right)\left(0.50\ \text{T}\right) \\
&= 3.2 \times 10^{-13}\ \text{N}
\end{aligned}
$$

Note that the negative sign for charge is not substituted into the equation.

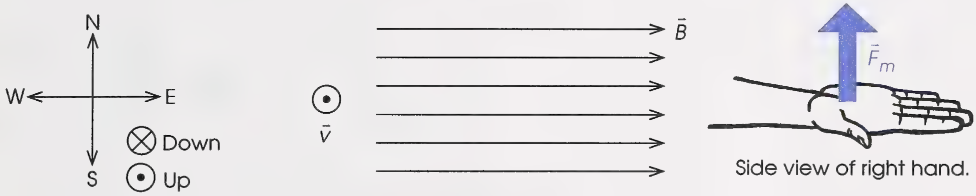
21. a.



The direction of the force on the electron is south.

b. $\vec{F}_m = 3.2 \times 10^{-13}$ N, south

22. a.



The direction of the force on the positive particles is north.

b. $q = 2(+1.60 \times 10^{-19}\ \text{C}) = +3.20 \times 10^{-19}$ C

$v = 3.0 \times 10^{4}$ m/s

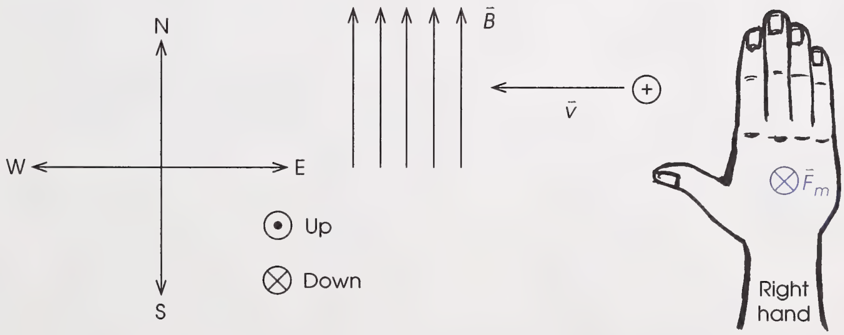
$B_\perp = 9.0 \times 10^{-2}$ T

$F_m = ?$

$$F_m = qvB_\perp$$
$$= (3.20 \times 10^{-19}\ \text{C})(3.0 \times 10^{4}\ \text{m/s})(9.0 \times 10^{-2}\ \text{T})$$
$$= 8.64 \times 10^{-16}\ \text{N}$$
$$= 8.6 \times 10^{-16}\ \text{N}$$

c. $\vec{F}_m = 8.6 \times 10^{-16}$ N, north

23. a.



The force is directed down, into the plane of the page.

b. $q = 3\left(+1.60\times10^{-19}\ \text{C}\right) = +4.80\times10^{-19}\ \text{C}$

$B_{\perp} = 4.0\times10^{-2}\ \text{T}$

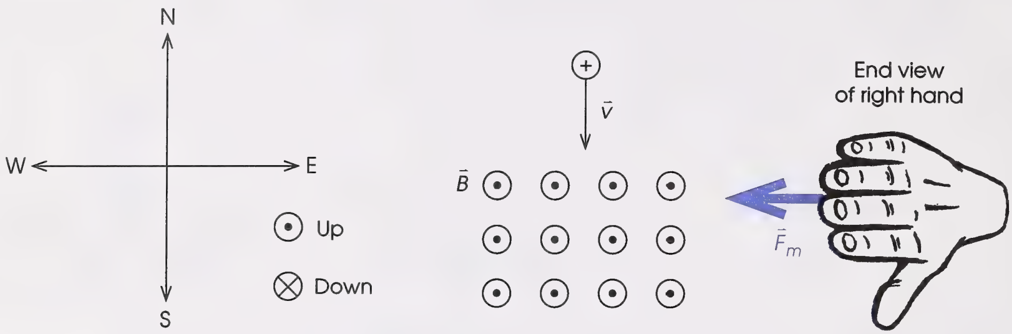
$v = 9.0\times10^{6}\ \text{m/s}$

$F_m = ?$

$$\begin{aligned} F_m &= qvB_{\perp} \\ &= \left(4.80\times10^{-19}\ \text{C}\right)\left(9.0\times10^{6}\ \text{m/s}\right)\left(4.0\times10^{-2}\ \text{T}\right) \\ &= 1.728\times10^{-13}\ \text{N} \\ &= 1.7\times10^{-13}\ \text{N} \end{aligned}$$

c. $\vec{F}_m = 1.7\times10^{-13}\ \text{N}$, down into the plane of the page

24. a.



The force will be directed to the west.

b. $q = 2\left(+1.60\times10^{-19}\ \text{C}\right) = +3.20\times10^{-19}\ \text{C}$

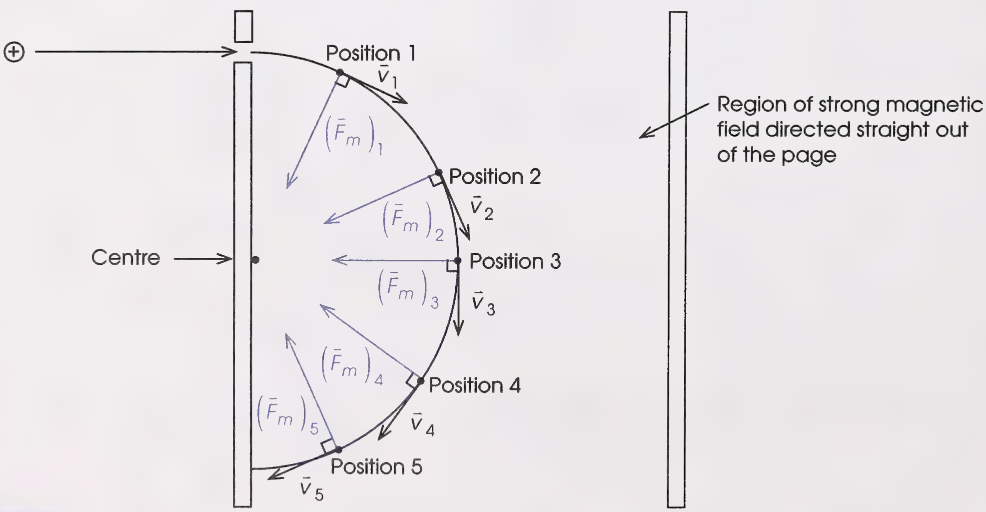
$v = 4.0\times10^{-2}\ \text{m/s}$

$B_{\perp} = 5.0\times10^{-2}\ \text{T}$

$$\begin{aligned} F_m &= qvB_{\perp} \\ &= \left(3.20\times10^{-19}\ \text{C}\right)\left(4.0\times10^{-2}\ \text{m/s}\right)\left(5.0\times10^{-2}\ \text{T}\right) \\ &= 6.4\times10^{-22}\ \text{N} \end{aligned}$$

c. $\vec{F}_m = 6.4\times10^{-22}\ \text{N}$, west

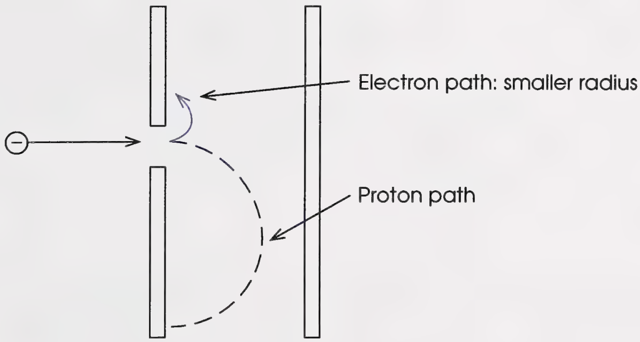
25.



26. The word *centripetal* literally means "centre-seeking". Centripetal forces always act at right angles to the instantaneous velocity vector and always point to the centre of the path. This is how a centripetal force is able to act on an object and only change the direction of the velocity, not the magnitude.

The previous diagram shows that the magnetic force always acts perpendicular to the instantaneous velocity and therefore it must always point to the centre of the circular path. In this example, the magnetic force acts as a centre-seeking, or centripetal, force.

27. If it was an electron that entered the field, the force would be in the opposite direction. The fact that the electron has a much smaller mass means that it has less inertia and could be turned into a tighter circle by the centripetal force, F_m.



28.

$$\boxed{F_m = F_c}$$

The magnetic force provides the centripetal force for circular motion.

Substitute.

$$\boxed{qvB_{\perp} = \frac{mv^2}{r}}$$

Rearrange.

$$\boxed{r = \frac{mv^2}{qvB_{\perp}}}$$

Simplify.

$$\boxed{r = \frac{mv}{qB_{\perp}}}$$

29. Textbook question 24. b.:

$q = +1.60 \times 10^{-19}\ \text{C}$
$B_{\perp} = 0.10\ \text{T}$
$v = 3.0 \times 10^{7}\ \text{m/s}$
$m = 1.67 \times 10^{-27}\ \text{kg}$
$r = ?$

$$\boxed{F_m = F_c}$$

The magnetic force provides the centripetal force for circular motion.

$$qvB_{\perp} = \frac{mv^2}{r}$$

$$\begin{aligned} r &= \frac{mv^2}{qvB_{\perp}} \\ &= \frac{mv}{qB_{\perp}} \\ &= \frac{(1.67 \times 10^{-27}\ \text{kg})(3.0 \times 10^{7}\ \text{m/s})}{(1.60 \times 10^{-19}\ \text{C})(0.10\ \text{T})} \\ &= 3.13\ \text{m} \\ &= 3.1\ \text{m} \end{aligned}$$

Textbook question 25. a.:

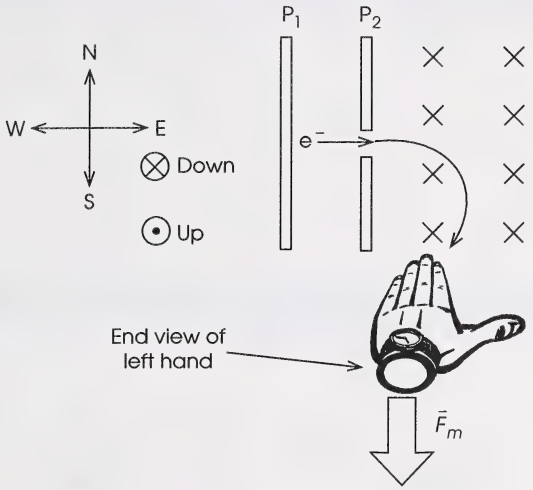
When the electron is accelerated between the two plates, the direction of the electric field between the two plates is P_2 to P_1. The electron accelerates from the negative plate, P_1, to the positive plate, P_2. The direction of the electric field is from the positive plate (P_2) to the negative plate (P_1), since this is the direction that a positive test charge would be forced.

Textbook question 25. b.:

$$\begin{aligned} \sum E_{before} &= \sum E_{after} \\ E_{electric} &= E_{mechanical} \\ Vq &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2Vq}{m}} \\ &= \sqrt{\frac{2(20\,000\ \text{V})(1.60 \times 10^{-19}\ \text{C})}{9.11 \times 10^{-31}\ \text{kg}}} \\ &= 8.38 \times 10^{7}\ \text{m/s} \end{aligned}$$

Textbook question 25. c.:

The electron will be forced to follow a circular path. As shown in the following diagram the electron would experience a southerly force at the instant it enters the region of strong magnetic field.



Section 2: Follow-up Activities

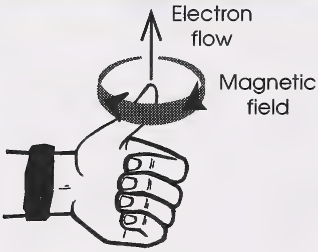
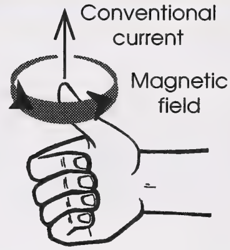
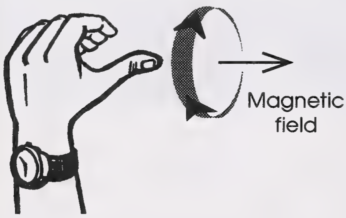
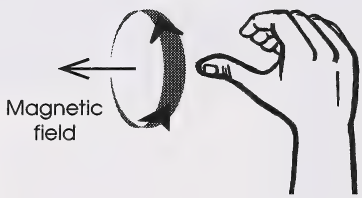
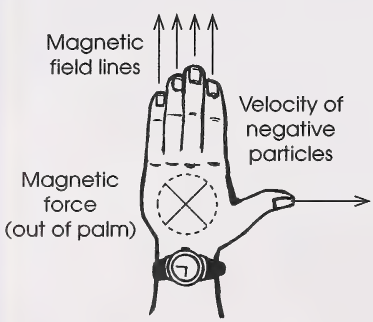
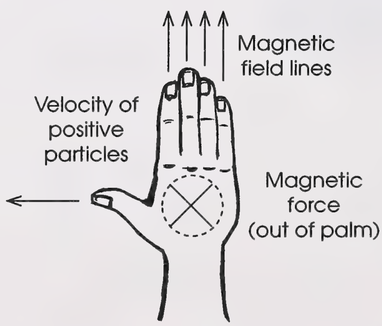
Extra Help

1.

Summarizing $F_m = I\ell B_\perp$			
Variable	**Symbol**	**Unit**	**How is this variable considered in the hand rule?**
Force	F_m	newtons	This vector comes out of the palm.
Current	I	amperes	This vector is represented by the thumb.
Length	ℓ	metres	This is not a vector and is not considered.
Magnetic Field	$B_\perp$	tesla	This vector is represented by the fingers.

Summarizing $F_m = qvB_{\perp}$			
Variable	**Symbol**	**Unit**	**How is this variable considered in the hand rule?**
Force	F_m	newtons	This vector comes out of the palm.
Charge	q	coulombs	The sign of the charge determines which hand to use.
Speed	v	metres per second	This vector is represented by the thumb.
Magnetic Field	$B_{\perp}$	tesla	This vector is represented by the fingers.

2.

Rule	Left Hand Version	Right Hand Version
Rule for Conductors		
Rule for Coils	Direction of electron flow in coils 	Direction of conventional current in coils 
Rule for Force		

Enrichment

1. a. Using the left-hand rule for force, the electrons should be deflected vertically up towards the top of the screen.

   b. Turning on the oscilloscope should verify your prediction. If you get different results, check that you are using your left hand and that the magnets have the correct polarity.

   c. In each case, proper application of the left-hand rule should predict the results demonstrated by the oscilloscope.

2. a. Liquid helium is very expensive and difficult to store.

   b. If the Japanese switch to the new higher temperature superconductors, they can use liquid nitrogen as the coolant. Liquid nitrogen is much cheaper.

NOTES

NOTES

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Module 5
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